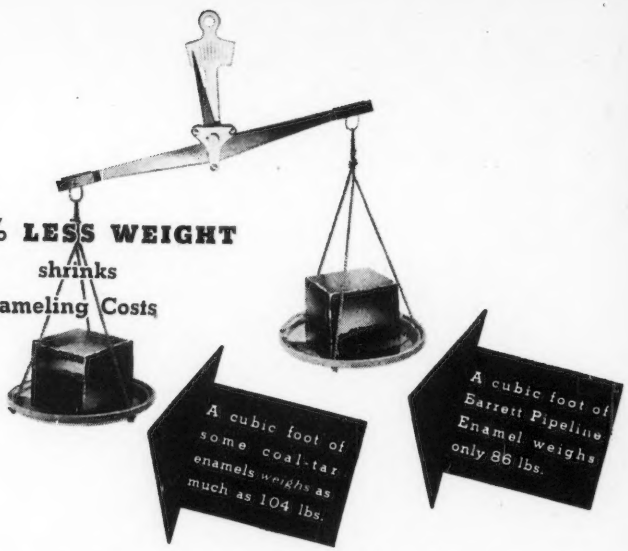
Corrosion



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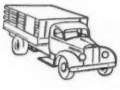

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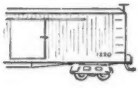

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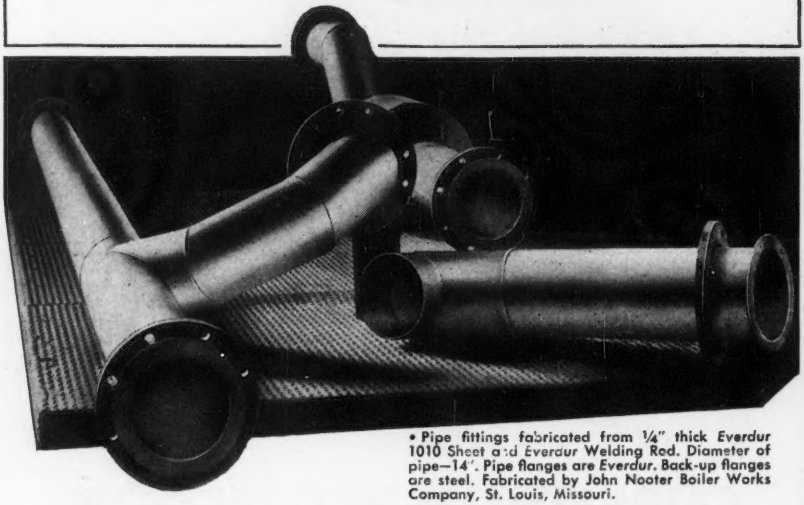

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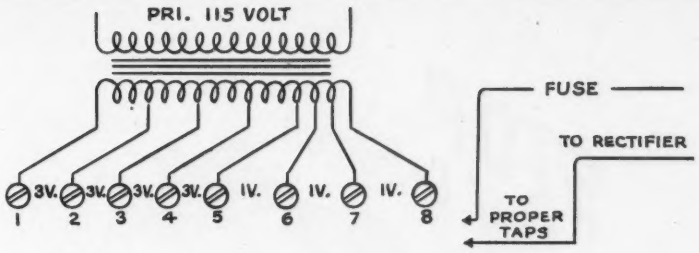

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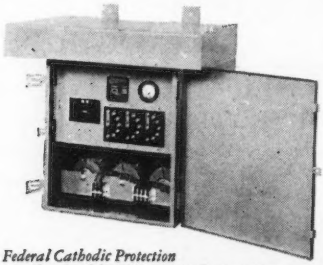

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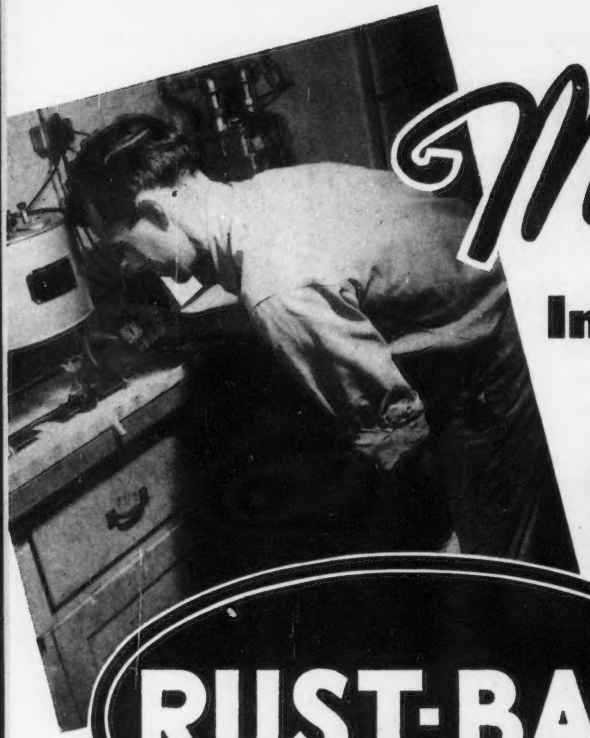

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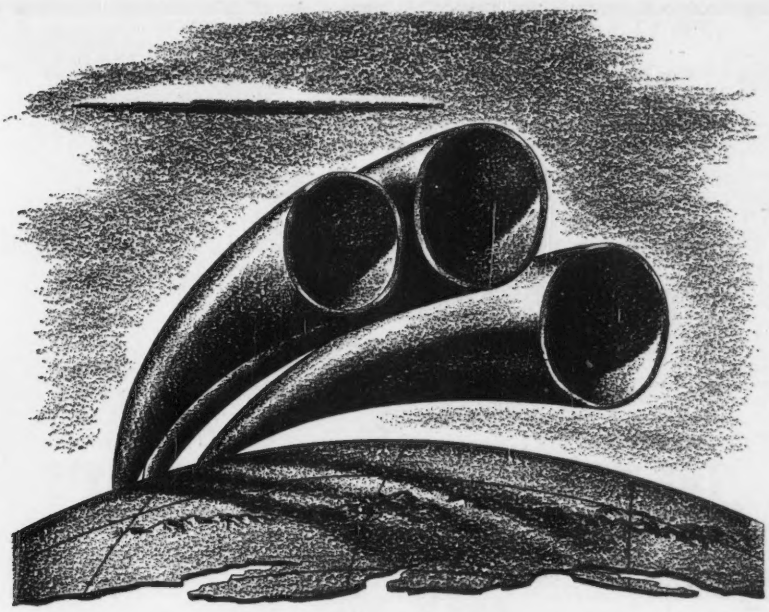

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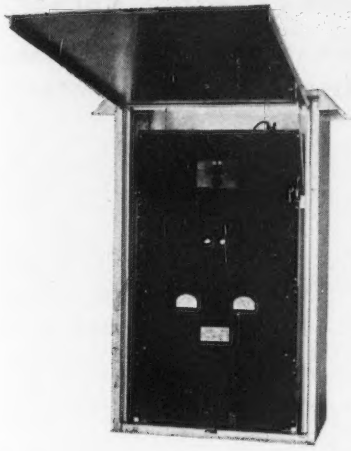

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An Official Publication of the

NATIONAL ASSOCIATION OF CORROSION ENGINEERS

A quarterly publication—to provide in permanent record the papers prepared for the Association, at meetings, annual conventions and from editorial sources.

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PUBLISHED QUARTERLY AT HOUSTON, TEXAS

Publication Office: 318 Southern Standard Building, Houston 2, Texas

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Organization Scope Expanded at St. Louis Session

Those participating in the organization of the National Association of Corrosion Engineers recognized that changes were inevitable when membership represented a cross-section of various fields where corrosion problems were encountered. From these added members of the Association have come suggestions pointing the way to requirements for a larger organization. Through the efforts of the Planning and Policy Committee, many of these suggestions have been incorporated into new "Articles of Organization and By-Laws" which will allow expansion and a better functioning organization.

We should first recognize that those serving on the Planning and Policy Committee have had extensive experience in association work and their combined efforts represent many years of such experience.

The submitted Articles of Organization were considered in a joint session by the Board of Directors and the Planning and Policy Committee at St. Louis, Missouri, on March 26-28, 1945. Members of the Planning and Policy Committee explained in this meeting that their proposed organization outline had been based upon the fundamental purposes for which this organization has been founded; i. e., securing advancement in corrosion mitigation and establishing standards of practice and terminology.

Any organization must be based primarily upon membership and four types have been designated in this reorganization: "Active Members" who will be individuals actively engaged and interested in corrosion mitigation; "Junior Members" which provides for individuals in the class of students; "Corporate Members" whch includes companies, institutions, or organizations interested or engaged in corrosion control and not primarily interested in the production or sale of corrosion mitigation equipment or products; and "Associate Memberships" which include companies, institutions, or organizations directly interested in the sale of corrosion mitigation equipment and products.

The governing body of this organization will be a Board of Directors composed of a president, vice president, treasurer, with elected directors as follows: one from each sectional or regional group, three from the Active membership, three from the Associate membership, three from the Corporate membership; and the Board will also include the latest living past president, Chairman of the Planning and Policy Committee, Chairman of the Publication Committee, Chairman of the Technical Committee, and Chairman of the Sectional Management Committee. When the new Board has been installed, one director only shall be elected each year for the separate representations mentioned above and serve for three years.

Two committees are provided which will function directly with the Board of Directors; viz., the Planning and Policy Committee and the Executive Committee. The Planning and Policy Committee will have the responsibility of long range planning in organization policies and recommend to the Board such changes as they deem necessary for the future. The Executive Committee will act and pass upon matters not requiring action by the Board of Directors, in order to minimize board meetings.

The new organization provides for the employment of a Secretary by the Board of Directors and this Secretary is charged with the responsibility of directing all routine procedure of the organization and shall be delegated to employ such additional help as is necessary. The Secretary is ex officio a member of all committees and is to be responsible for the recording of minutes and proceedings for any meetings. At present, he will also be responsible for the supervision of the Association's official publication.

Provisions are made in this reorganization for the immediate creation of three principal committees, to be designated the Technical Committee, the Sectional Management Committee, and the Publication Committee.

The Technical Committee, the body or group around which the organization is built, has the function of directing all subcommittees created and assigned to specific problems of the organization. These problems will include investigations which will lead to advancement in corrosion control, and recommending standards of practice and terminology. This Committee will review the work of all subcommittees and make recommendations for furtherance of the work if necessary, or forward the reports of subcommittees to the Board of Directors with their recommendations. The Technical Committee is defined to allow the creation of the necessary subcommittees to deal with new problems as they arise.

The Regional Management Committee is charged with the administration of sectional groups which are to be organized to facilitate meetings within smaller geographical areas. The provisions now made in the new articles of Organization require that limitations be placed upon the number of areas organized in order to prevent an undue enlargement of the Board.

The Publication Committee will share responsibility with the Secretary in promoting the publication of CORROSION or other association publications and in maintaining the desired standards of publication.

The proposed reorganization was discussed in open meeting at St. Louis after it had been considered by the Board of Directors and differences of opinion voiced as to some of the provisions set out; however, the objections brought up may be corrected by Board action.

It is to be noted that the Articles of Organization and By-Laws have been patterned in a manner that will allow corrections or alterations when necessary but, as pointed out by the Planning and Policy Committee, these

corrections and/or alterations will neither be too easy nor too difficult to make.

It is realized that it will be difficult to draw up a document which will meet with unanimous approval of a large group and it would seem that the organization should recognize the experience of those who have submitted this reorganization plan and give support to this revised organization equal to that indicated by the response in the letter ballot which authorized the Board of Directors to adopt necessary changes for this growing association. As of June 1, 1945, the N. A. C. E. functions under the reorganization plan.

The new Articles of Organization and By-Laws appear in this number of CORROSION, beginning on page 28, second advertising section.

Corrosion

An Official Publication of the
NATIONAL ASSOCIATION OF CORROSION ENGINEERS

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Volume 1 **JUNE, 1945** **Number 2**

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Subscription: $3.00 per year to non-members. $2.00 of members' dues are applied as subscription to CORROSION. Additional single copies to members 50 cents, to non-members 75 cents. All correspondence to the publication should be addressed to The Executive Secretary, NACE, 318 Southern Standard Building, Houston 2, Texas

Corrosion Protection for Transcontinental Cable West of Salt Lake City, Utah

By T. J. Maitland
American Telephone & Telegraph Company, Long Lines Department

IN 1941 the Bell System started construction of buried cable between Omaha, Nebraska, and the West Coast. This cable route traverses the plains of Nebraska, the mountains of Wyoming and the salt flats of Utah as well as the rugged country of Nevada and California. Many unusual construction problems were met and solved during this undertaking, which was completed in 1942. The cable was plowed into the ground using special equipment instead of being placed in conduit as normally installed in city streets.

Among the problems connected with the placing of the cables along this route was that of possible corrosion of the buried cables. The experience of several oil and gas companies having underground pipe lines near the proposed route of these cables was found to be very useful in solving our problem. Their experience indicated that more substantial protection against sheath corrosion than that afforded by the usual type of buried cable protection previously employed would be desirable for a considerable portion of the route, particularly where alkali soil conditions are prevalent.

The protection applied to the lead sheath of buried telephone cables prior to this project generally consisted of layers of asphalt-impregnated Sisalkraft paper over which wrappings of jute were placed. In areas where rodents such as pocket gophers are present, a thin steel tape was placed between the kraft paper and the jute to prevent the gophers from chewing holes in the lead sheath.

To provide greater protection in the corrosive soils expected to be encountered along the transcontinental cable route and to minimize mutual effects of drainage on cables and pipe lines, a special protective covering was developed by the Bell Telephone Laboratories. This covering consisted of a thermoplastic compound made up in part of reclaimed rubber. The coating, a single layer of approximately 60 mils thickness, was applied using a special cement over the lead sheath of steel gopher tape. The thermoplastic was then covered with a fabric tape to prevent mechanical injury during placing operations. Cross-sections of the jute and thermoplastic covered cables are shown in Figure 1.

This thermoplastic protection performs the same general function as the protective coatings applied to pipe lines for corrosion protection. It was realized that this protective coating would not provide perfect

insulation, but it was expected the locations of any faults in the coating could be found by electrical measurement.

The electrical method of locating points of low insulation or "holidays," has in general proven satisfactory, but in some of the gopher

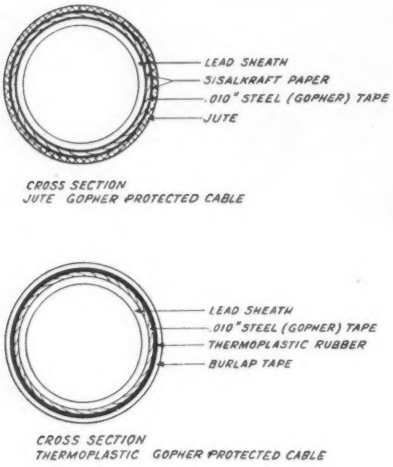


Figure 1.

infested areas, particularly in Nebraska, the thermoplastic covering has been attacked by these rodents to such an extent that continuous repairs will be necessary to maintain the effectiveness of the covering. A supplemental means of protecting the cable sheath and gopher tape from corrosion has, therefore, been considered necessary.

The first method used for supplemental protection consisted of the application of cathodic protection applied by means of rectifiers draining current from the cable sheath to current-carrying grounds located at alternate repeater locations along the cable route. These repeaters are spaced approximately 17 miles apart, so that a small amount of current drained from the cable sheath at alternate stations was considered ample to protect the cables throughout the section under normal conditions. In the area along the Platte River Valley in Nebraska, this means has been employed and where gopher depredations are excessive it has been found desirable to install this forced drainage at more frequent intervals. This method has been used effectively in the past for protection of lead cable in conduit and its application is well known by corrosion engineers.

West of Salt Lake City, Utah, however, it was found that the low earth resistivity in the area through which the cables pass resulted in cable-to-earth resistance values for the thermoplastic covering very much less than expected. For example, in the 120 route miles of thermoplastic protected cables in Nebraska and the 400 miles in Wyoming, it was found that a leakage resistance value of 100,000 ohm-feet could be readily obtained whereas west of Salt Lake City a value of 25,000 ohm-feet was obtained with difficulty. The presence of sodium salts in the area west of Salt Lake City also precluded the use of the usual type of rectifier and ground installation mentioned previously, due to the necessity of setting up excessive negative potentials between cable sheath and earth in the vicinity

of the rectifier installations. The high negative potential in an alkali salt electrolyte produces a strong alkaline solution at the cable sheath and creates conditions conducive to cathodic corrosion of the lead. This problem is not encountered in connection with pipe line protection

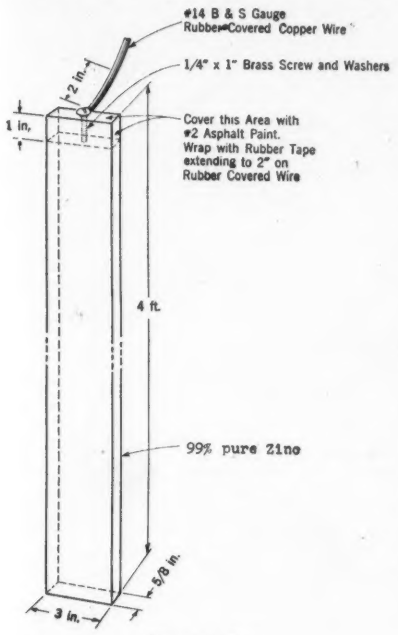


Figure 2.

since iron is not attacked by an alkaline solution when held at a negative potential.

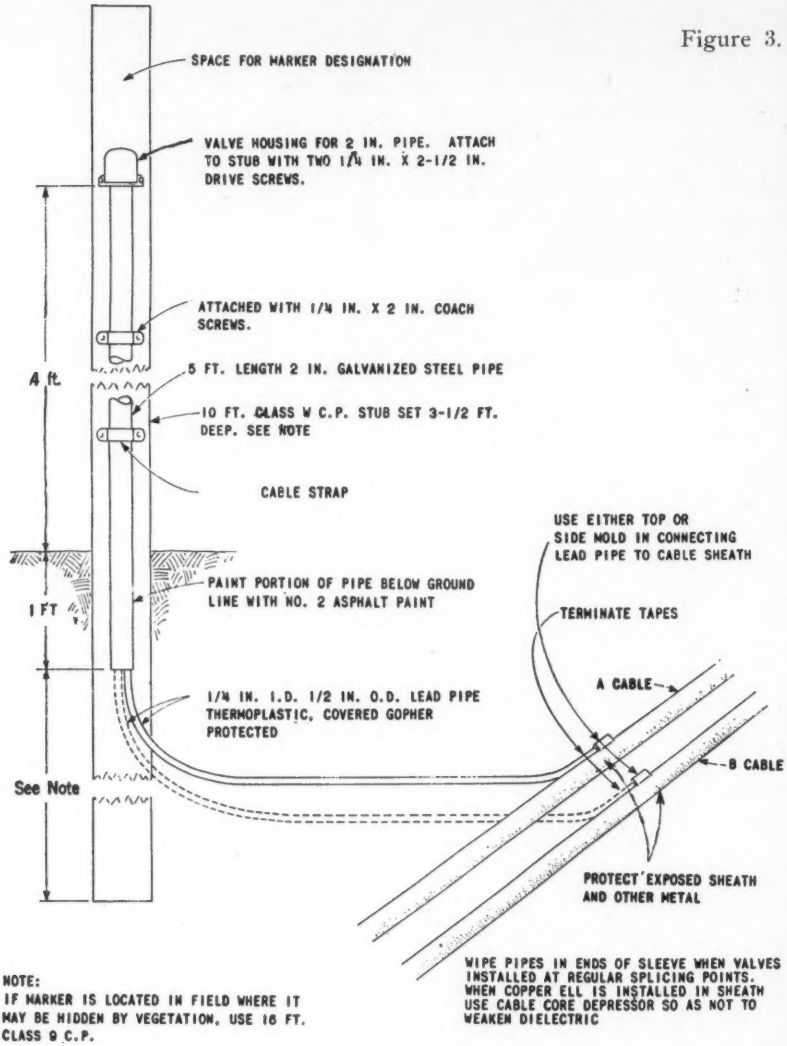
Consideration of this problem introduced the possibility of using zinc as a means of providing forced drainage which, due to the greater number of drainage points, would not result in the high negative cable sheath-to-earth potentials at each drainage point normally encountered with the use of rectifiers. Accordingly, a trial installation was made using bars of 99% pure zinc for this purpose. These bars were each approximately 4 feet in length, 3 inches in width and $\frac{5}{8}$ inch in thickness and weighed about 24 pounds. Each bar was prepared for installation by drilling and tapping a hole in one end about 1 inch deep for insertion of a $\frac{1}{4}$" brass screw. A No. 14 B & S gauge rubber-covered copper wire was then connected under the head of the brass screw. The area around the end of the bar to the depth of the screw and connections were coated with a liberal application of asphalt paint. A wrapping of rubber tape was applied near the point of contact with the zinc anode to protect against possible galvanic action between the zinc and the copper or brass causing unnecessary corrosion of the zinc. The arrangement of this anode is shown in Figure 2. For future installations it is planned to drill and tap each end of the zinc bars so that wire leads may be connected to both ends of the anodes to insure obtaining as much uniformity of corrosion as possible from the zinc.

Typical Analysis, Salt Soil in Area

Sodium & Potassium Chloride, ppm	169,000
Calcium Sulfate	3,500
Calcium Chloride	1,300
Magnesium Sulfate	2,500
Magnesium Chloride	1,100

In the alkali salt soil west of Salt Lake City the zinc bars were found to have an open circuit potential of approximately 0.50 volt negative to lead and when connected by means

Figure 3.


SPACE FOR MARKER DESIGNATION
VALVE HOUSING FOR 2 IN. PIPE. ATTACH TO STUB WITH TWO 1/4 IN. X 2-1/2 IN. DRIVE SCREWS.
ATTACHED WITH 1/4 IN. X 2 IN. COACH SCREWS.
4 ft.
5 FT. LENGTH 2 IN. GALVANIZED STEEL PIPE
10 FT. CLASS W C.P. STUB SET 3-1/2 FT. DEEP. SEE NOTE
CABLE STRAP
USE EITHER TOP OR SIDE MOLD IN CONNECTING LEAD PIPE TO CABLE SHEATH
PAINT PORTION OF PIPE BELOW GROUND LINE WITH NO. 2 ASPHALT PAINT
1 FT
TERMINATE TAPES
A CABLE
1/4 IN. I.D. 1/2 IN. O.D. LEAD PIPE THERMOPLASTIC, COVERED GOPHER PROTECTED
B CABLE
See Note
PROTECT EXPOSED SHEATH AND OTHER METAL
WIPE PIPES IN ENDS OF SLEEVE WHEN VALVES INSTALLED AT REGULAR SPLICING POINTS. WHEN COPPER ELL IS INSTALLED IN SHEATH USE CABLE CORE DEPRESSOR SO AS NOT TO WEAKEN DIELECTRIC
NOTE:
IF MARKER IS LOCATED IN FIELD WHERE IT MAY BE HIDDEN BY VEGETATION, USE 16 FT. CLASS 9 C.P.

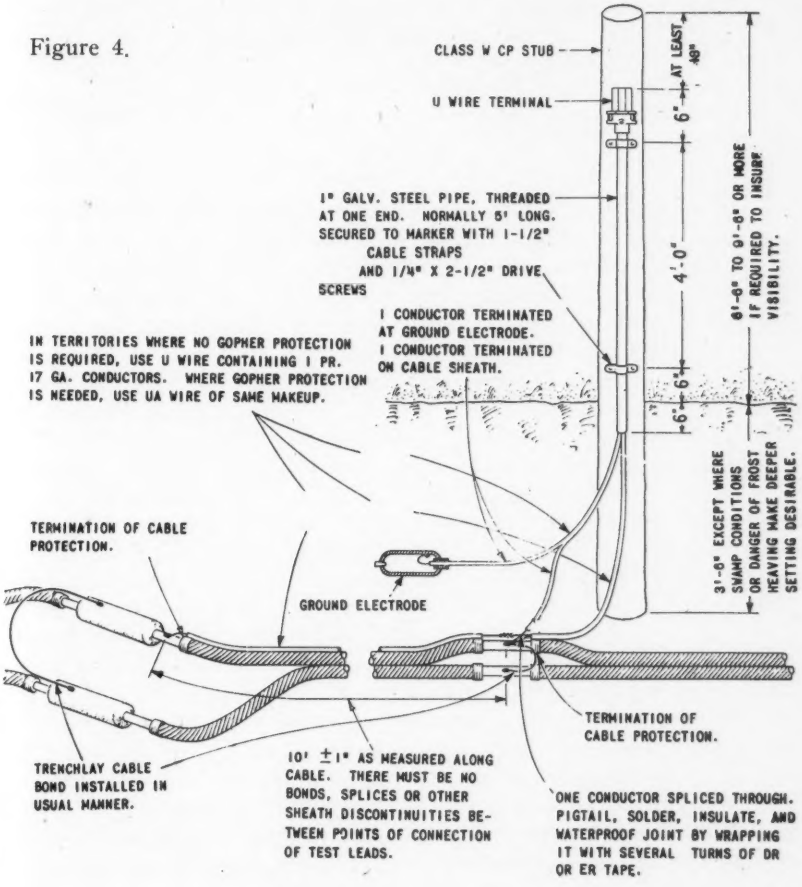
of an insulated wire to the lead cable, sheath current flowed from the lead sheath to the zinc bar over the wire. The magnitude of the current delivered to the anode was of course largely dependent upon the resistance of the earth in which the zinc was placed.

The transcontinental cables were in general placed at a depth of approximately 30 inches below the surface of the ground. To measure the

pressure of the nitrogen gas under which these cables are maintained air valves are mounted on marker posts about every 3,000 feet along the cable route. These valves are connected to the main cables by lengths of lead pipes between the cables and the marker posts. The arrangement at valve points is shown in Figure 3.

Electrolysis test points are installed along this cable route at approximately 3-mile intervals. At these points connection was made to the cable sheath with two insulated wires which were terminated on marker posts along the cable route. A permanent lead electrode approximately 2 feet in length was also buried at each electrolysis test point at the same depth as the main cable and approximately 5 feet from

Figure 4.


CLASS W CP STUB
U WIRE TERMINAL
6" AT LEAST
1" GALV. STEEL PIPE, THREADED AT ONE END. NORMALLY 5' LONG. SECURED TO MARKER WITH 1-1/2" CABLE STRAPS AND 1/4" X 2-1/2" DRIVE SCREWS
4'-0"
6'-6" TO 9'-6" OR MORE IF REQUIRED TO INSURE VISIBILITY.
1 CONDUCTOR TERMINATED AT GROUND ELECTRODE.
1 CONDUCTOR TERMINATED ON CABLE SHEATH.
IN TERRITORIES WHERE NO GOPHER PROTECTION IS REQUIRED, USE U WIRE CONTAINING 1 PR. 17 GA. CONDUCTORS. WHERE GOPHER PROTECTION IS NEEDED, USE UA WIRE OF SAME MAKEUP.
6"
6"
3'-0" EXCEPT WHERE SWAMP CONDITIONS OR DANGER OF FROST HEAVING MAKE DEEPER SETTING DESIRABLE.
TERMINATION OF CABLE PROTECTION.
GROUND ELECTRODE
TERMINATION OF CABLE PROTECTION.
TRENCHLAY CABLE BOND INSTALLED IN USUAL MANNER.
10' ±1" AS MEASURED ALONG CABLE. THERE MUST BE NO BONDS, SPLICES OR OTHER SHEATH DISCONTINUITIES BETWEEN POINTS OF CONNECTION OF TEST LEADS.
ONE CONDUCTOR SPLICED THROUGH. PIGTAIL, SOLDER, INSULATE, AND WATERPROOF JOINT BY WRAPPING IT WITH SEVERAL TURNS OF DR OR ER TAPE.

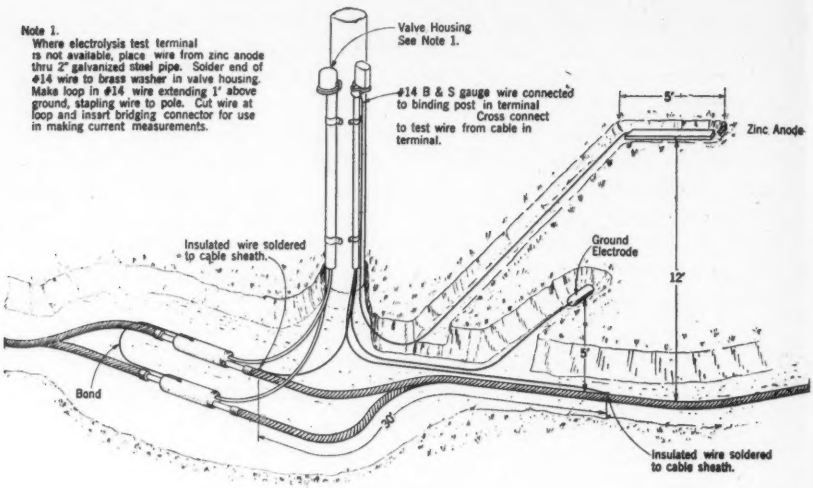

Note 1.
Where electrolysis test terminal is not available, place wire from zinc anode thru 2" galvanized steel pipe. Solder end of #14 wire to brass washer in valve housing. Make loop in #14 wire extending 1' above ground, stapling wire to pole. Cut wire at loop and insert bridging connector for use in making current measurements.
Valve Housing
See Note 1.
#14 B & S gauge wire connected to binding post in terminal
Cross connect to test wire from cable in terminal.
5'
Zinc Anode
Insulated wire soldered to cable sheath.
Ground Electrode
12'
Bond
Insulated wire soldered to cable sheath.

Figure 5.

it. This electrode or lead plate is used in measuring cable-to-earth potential. Current on the cable sheath may be measured by means of the potential over the length of cable sheath to which the two insulated wires are connected. The arrangement at electrolysis test points is shown in Figure 4.

From a practical standpoint it will be seen that the installation of the zinc anodes was limited to locations where sheath connections were accessible such as these valve and electrolysis test points.

Installation of Zinc Anodes

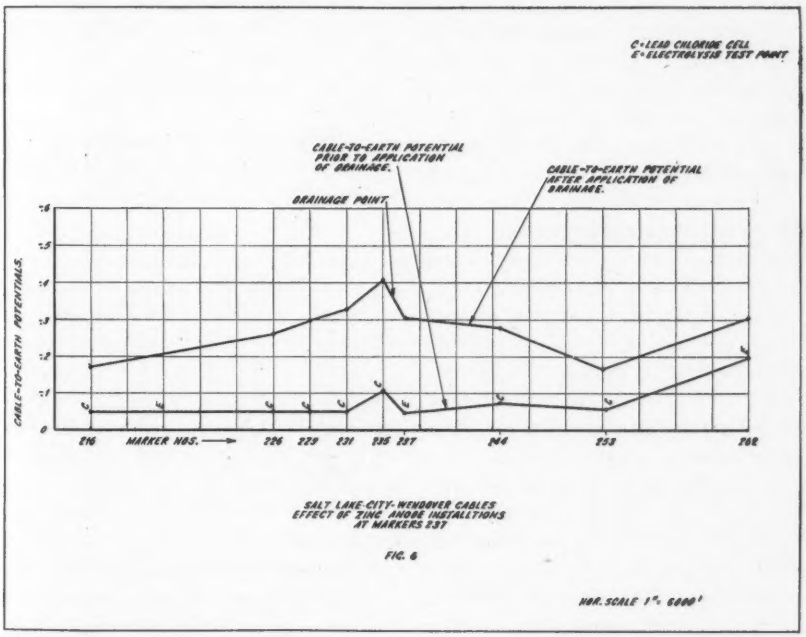
As mentioned previously, insulation measurements of the thermoplastic protection west of Salt Lake City gave values only about one fourth those in other sections. These conditions were indicated by cable-to-earth resistance measurements made at the valve points which gave resistances of from 0.6 to 1.0 ohm as compared to 2.0 ohms and higher in other areas. In view of these low resistance values it was not expected that the effect of the zinc anodes would extend for a very great distance from a single location and plans were originally made for the trial installation of the zinc anodes on the basis of connecting a zinc bar at alternate valve locations. The initial section selected for test extended over a distance of about 15 miles, or from a point approximately 35 miles to a point about 50 miles west of Salt Lake City. This section was selected because it had particularly low cable-to-earth resistance and because it was considerably distant from any known sources of stray direct current.

In order to measure cable-to-earth potentials at each valve point, lead

chloride half-cells were used as their single potential does not change with time whereas newly installed lead plates would take some time to become acclimatized. These cells consist of a solution of lead chloride in agar-agar jelly included in a glass tube open at one end and with a lead electrode extending into the lead-chloride solution at the other. Connection is made to the lead electrode by means of a length of rubber-covered wire.

These half-cells were located at consecutive valve locations for a distance of approximately two miles each side of the point where the first zinc anode was placed. Measurements were made of cable-to-earth potential at each of these points prior to the installation of the zinc anode.

The first zinc anode installation was then made at an electrolysis test point approximately three miles east of the 50 mile point at a location selected from inspection of the territory and from the results of previous tests which indicated low insulation resistance for the thermoplastic covering in its immediate vicinity. The zinc anode was buried horizontally in a trench about three feet deep parallel to and 12 feet north of the cables. The arrangement is shown in Figure 5. This location was close to the bank of a stream flowing into Salt Lake. Initial tests showed a current of 0.22 ampere in the connecting wire from the cable to the buried



zinc anode. This current rapidly declined and within 15 minutes had reached a steady value of 0.14 ampere. Tests were then made of the cable-to-earth potentials at the valve points each side of this anode installation. The results of the two sets of readings are shown in Figure 6.

It was found by tests that the potentials between the cable sheath and the earth had changed 0.22 volt at a point two miles from the anode installation. Additional half-cells were then installed at a number of more remote valve points and it was found that the installation of this one zinc anode had changed the cable-to-earth potentials 0.124 volt at at point approximately four miles away.

It was decided to make the second zinc anode installation approximately nine miles east of the first installation instead of one mile away as originally planned. Accordingly, a second installation was made about 38 miles west of Salt Lake City. This installation was similar to the first except that the zinc was located in wet soil near the edge of Salt Lake. The initial current drained from the cable at this point was 0.18 ampere. After a period of five minutes it had dropped to 0.16 ampere, where it remained steady for an observed time of 35 minutes. Test points were then established over the remainder of the 15-mile section and it was found that the second installation was also effective over a comparable distance; the cable-to-earth potentials being changed 0.090 volt 3½ miles east of the zinc connection point and 0.095 volt four miles west of the zinc connection point. The greatest effect of these connections on cable-to-earth potentials was, of course, observed at the point of connection to the zinc and was approximately 0.32 volt in each case.

The experiment was then extended to the entire buried cable route between Salt Lake City and Wendover, Utah, a distance of approximately 120 miles. This was done by locating zinc anodes at from 11- t 15-mile intervals throughout the en tire distance.

In one 16-mile repeater section, however, the thermoplastic covering was initially found to be above the estimated minimum requirements as indicated by cable-to-earth resistance measurements so that zinc anodes were not installed in this section.

Table I shows the location, resistance-to-earth and current drained initially from each installation.

TABLE I

LOCATION	Distance from Salt Lake City U.G., Miles	Resistance of Zinc Anode Ohms	Current Drained Amp.
Marker 77	12.0	1.60	0.120
Marker 195	34.0	1.70	0.160
Marker 237	43.5	1.05	0.140
Marker 280	52.5	5.80	0.035
Marker 358	67.5	7.00	0.040
Marker 419	81.5	1.30	0.240
Marker 457	92.5	1.25	0.180
Marker 492	104.0	1.55	0.150
Marker 524	117.0	1.25	0.200
Utah-Nevada State Line	121.0	....	.....

At one of the above locations (Marker 280) it was found that the resistance-to-earth of a single zinc anode was so high (15 ohms) that

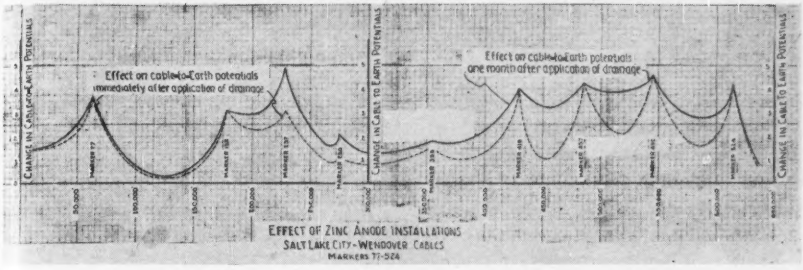

Effect on cable-to-earth potentials immediately after application of drainage
Effect on cable-to-earth potentials one month after application of drainage
CHANGE IN CABLE-TO-EARTH POTENTIALS
EFFECT OF ZINC ANODE INSTALLATIONS
SALT LAKE CITY - WENDOVER CABLES
MARKERS 77-524

Figure 7.

the initial current drained was only in the order of 0.020 ampere. This location was very dry and it was found impracticable to obtain permanently moist ground near this point. The condition was, therefore, improved by adding an additional zinc anode located on the opposite side of the cable route from the first anode and about 12 feet from the main cables. It is expected that automatic adjustment of the drainage current will be obtained in the wet season.

The effect of the various installations on the cable-to-earth potentials is shown in Figure 7.

After the cables were connected to the two initial anodes (Markers 195 and 237) for a period of one week, potential measurements from cable to earth were repeated at electrolysis test points in the section affected. Figure 8 shows the results of the initial effect on cable-to-earth potentials and the effect one week after the installation was completed in this area.

One month after the installations were completed measurements were again made of cable-to-earth potentials at each electrolysis test point throughout the entire area and of the current delivered to each anode. The results at each anode installation are shown in Table II.

TABLE II

LOCATION	Current Drained. Amp.	Total Effect on Cable-to-Earth Potentials Volt
Marker 77	0.080	0.34
Marker 195	0.100	0.36
Marker 237	0.020	0.50
Marker 280	0.035	0.20
Marker 358	0.020	0.18
Marker 419	0.030	0.36
Marker 457	0.020	0.40
Marker 492	0.030	0.40
Marker 524	0.100	0.30

The results of measurements of cable-to-earth potentials in the area affected by the zinc anodes at Markers 195 and 237 one month after they were placed are shown in Figure 9.

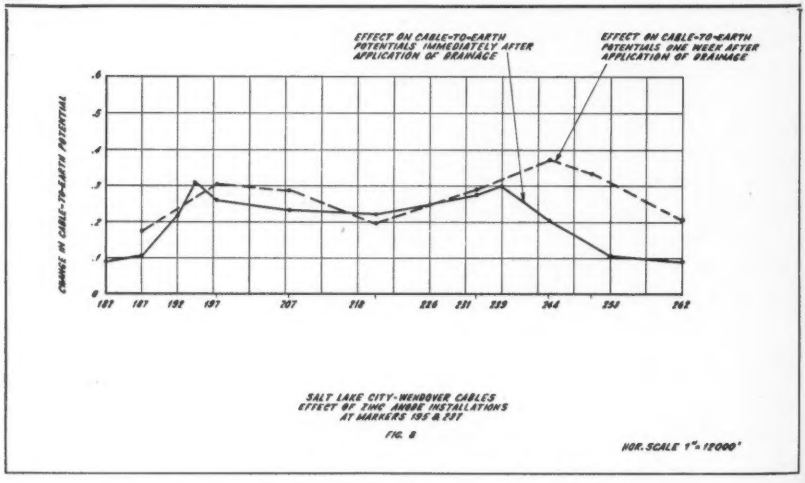
Discussion of Results

It will be noted from the above tables that the current delivered to the zinc anodes at practically all installations decreased considerably during the month's elapsed time. However, the readings of cable-to-earth potential showed a general increase in magnitude above the measurements made immediately after the anodes were connected. For ex-

ample at Marker 504 the cable-to-earth potential immediately after the anodes at Markers 492 and 524 were connected was —0.10 volt, one month after the anodes were installed the reading was —0.27 volt. In the section where cable-to-earth potential measurements were made a week after the original installation, no appreciable change in cable-to-earth potential occurred during the remaining three weeks.

These results are interpreted as indicating the effect of polarization of the cable. As polarization increased with time, the cable-to-earth potentials increased and the current drained by the zincs materially decreased. It is, of course, possible that the zinc anodes may in time become passive, and will no longer be effective as a current delivery. However, since these installations were made in a sodium chloride environment and as zinc chloride is soluble it is not believed this will happen. No special environment material was used, therefore, in these installations. Based upon 100% corrosion efficiency the life of the zinc bars in years should theoretically be approximately 1.46 times the reciprocal of the current delivered. In other words a zinc bar weighing 24 pounds would be completely disintegrated in a period of 7.3 years when delivering a current of 0.20 ampere continuously. It is not expected, however, that the theoretical figure will be attained and at some time in the future, probably one year after installation, some of these zinc anodes will be removed from the ground for inspection and weighing. The future frequency of inspection will be based upon these results.

It is interesting to note the effect of the installation of these zinc anodes on the apparent cable-to-earth resistance. Table III below gives a comparison of these values at each anode installation under the



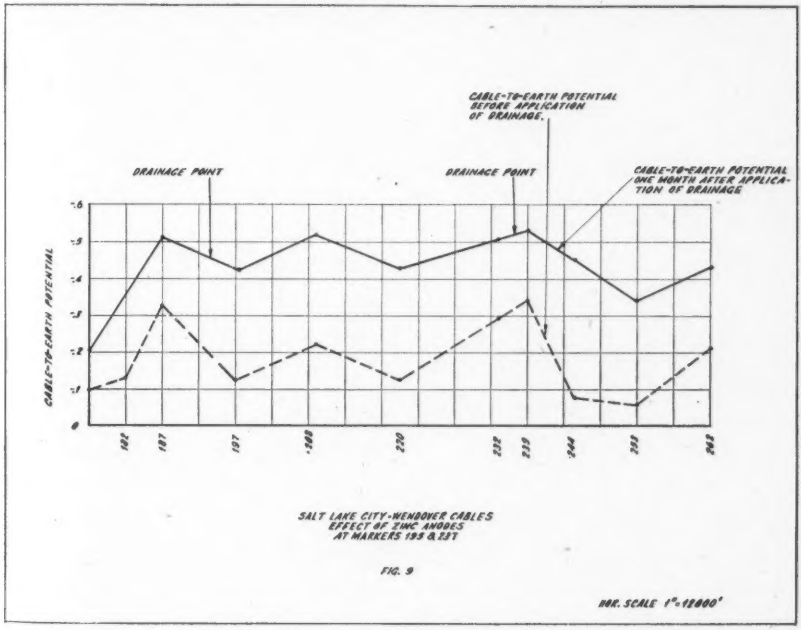
various conditions indicated.

TABLE III

LOCATION	Cable-to-Earth Resistance Prior to Anode Installation Ohms	Apparent Cable-to-Earth Resistance Immediately After Anode Installation Ohms	Apparent Cable-to-Earth Resistance One Month After Anode Installation Ohms
Marker 77	1.10	3.00	4.25
Marker 195	0.78	1.91	3.60
Marker 237	0.60	2.28	25.00
Marker 280	1.45	3.06	5.72
Marker 358	2.02	3.50	9.00
Marker 419	0.88	1.41	12.00
Marker 457	1.00	2.08	20.00
Marker 492	1.20	2.68	13.30
Marker 524	1.00	2.25	3.00

The increase in apparent cable-to-earth resistance is believed to be due to the polarization of the cable sheath as drainage to the zinc anodes continued. It is known that polarization of lead sheath may take some time, and the changes in apparent resistance are indicative of this. As current is drained from a single installation the sheath immediately adjacent to the anode connection is polarized and the current decreases slightly, the drainage current is then effective over a greater distance with resultant extension of the polarization effects. This procedure will continue until the effects from the adjacent anodes overlap.

The comparatively small change in the apparent resistance values at Markers 77 and 195 is believed to be due in part to a fault in the thermoplastic coating in the vicinity of Marker 77 and in part to the distance between the installations. Marker 524 is near the Utah-Nevada State Line, beyond which the cables are known to be grounded at several locations, and it is believed this con-



dition is responsible for the lower values at this point. It will also be noted that the minimum change in resistance occurred where the current flow to the anodes changed the least. It is possible that complete polarization had not taken place along these sections of cable and later measurements may show some change in these values.

Conclusions

The location and conditions under which the zinc bars were used as anodes in this instance appear to be nearly ideal, as the earth resistivity was low and the apparent cable-to-earth resistivity comparatively high and uniform. From the results to date its application in this particular area is considered quite successful, but the behavior of the zinc anodes for cable protective purposes under other conditions has not yet been determined.

In so far as this one area is concerned the zinc anodes are considered to have the following advantages over other methods of providing forced drainage protection for the cable:

1. Economy of Material — Zinc bars of the size used are relatively inexpensive.

2. Ease of Installation—Approximately two man hours were required to prepare and install a zinc anode at a single location.

3. Minimum Maintenance—Under normal conditions it is not expected that these anodes wil require replacement for several years and replacement can be made at relatively small cost. Interruptions of drainage current due to power failures, etc., are non-existent.

It is also believed from the results of the few installations made along this cable route that this method of protection has a number of limitations including the following:

1. Requires a low resistance ground. Where earth resistivity is relatively high a large number of anodes, or the construction of a special environment, would be required to produce a measurable flow of current.

2. Zinc may become passive requiring frequent treatment. This could become a considerable maintenance item if the condition occurred frequently.

3. A comparatively well-insulated covering is necessary over the cable sheath to insure effective results over an appreciable distance. If a well-grounded cable sheath is involved the anode installations would be effective over a much shorter distance and the economy of the method might accordingly be seriously affected.

The use of zinc anodes as a means of corrosion protection for lead cable sheath has been attempted several times in the past for cables in conduit with inconclusive results. As far as the writer is aware this is the first attempt to utilize zinc anodes as a means for protection of buried cable. From the results obtained to date it is considered that the future of this method offers interesting possibilities and it is planned to extend its use on buried cable plant where conditions warrant.

Developing Magnesium for Cathodic Protection

By Porter Hart and Yale W. Titterington
Texas Division, The Dow Chemical Company

MAGNESIUM, because of its position in the electrochemical series, has long been thought of as an ideal source of current for cathodic installations. Adding credence to this belief is its high electrochemical equivalent of 1,000 ampere-hours per pound and solution potential to a $CuSO_4$ electrode of from 1.8 to 1.7 volts depending upon whether commercially pure or alloyed material is used. By comparison, zinc has an electrochemical equivalent of 372 ampere-hours per pound and a solution potential of approximately 1.1 volts.

From the ratio of electrochemical equivalents, it is evident that magnesium at a current efficiency of only 33⅓% would be equivalent to zinc at a current efficiency of 90%. However, much higher efficiencies than this have been obtained on magnesium in field installations. It is to be noted that the difference in solution potentials of the metals is an additional factor to be considered. Assuming that the theoretical protective potential of a pipe is 0.85 volts, referred to a $CuSO_4$ electrode, then the open circuit potential of magnesium to iron would be 0.95 volts; whereas, if zinc anodes were used this potential would be only 0.25 volts. This gives a comparative driving potential ratio of 3.8 to 1. In terms of installation, this means that one magnesium anode station would give the same current output as 3.8 zinc anode stations of similar size.

Some five or six years ago The Dow Chemical Company's Physical Research Laboratory at Midland, Michigan, undertook an investigation to determine how magnesium anodes would perform under actual field conditions. These earlier tests demonstrated that magnesium had both possibilities and limitations for this application. The current output was ample and there was no evidence of polarization, but the operating efficiency fell far short of the theoretical output of 1,000 ampere-hours per pound.

Since then, an extensive research program has been carried out to determine how magnesium anodes could be made to perform more efficiently and how their life could be extended in field applications.

Laboratory investigations indicate that the efficiency and life of such an anode is largely dependent upon three factors, namely:

1. Composition
2. Backfill
3. Current density

The effect of composition is that the percentage of iron, nickel, and copper above a definite maximum

tends to accelerate the local cell corrosion of the anode.

The selection of a backfill material is particularly important in that herein lies the greatest opportunity of reducing local cell corrosion of the anode surface. One specific example of the effect of the electrolyte on the performance of magnesium anodes is that chromates in the absence of chlorides give excessive polarization and seriously restrict the current output.

Current efficiency increases with current density up to some maximum value, primarily because the percentage of local corrosion to useful current decreases. At a current density of 200 milliamperes per square foot, the current efficiency will be approximately 50%.

Initial Field Installations

The work of the Texas Division at Freeport has been fully devoted to field installations. This program was initiated in 1940 by The Dow Chemical Company, in requesting Starr Thayer to use magnesium in the protection of one of their field gas lines.

The initial project was the application of cathodic protection to 41.5 miles of 8-inch gas line, covered with coal tar enamel and 15 lb. felt wrapper, using commercially pure magnesium anodes 1.3 inches in diameter from 6 to 10 feet in length. This installation was completed in October, 1940, just a few months after the pipe line had been laid. Complete protection of this pipe line was achieved at this time through the use of 20 anodes distributed throughout four stations. The current output per station ranged from 0.3 to 3.6 amperes with the total current drain being 6.25 amperes. Little additional information is available on this installation other than that the anodes were placed in a lime slurry. However, the use of this type of backfill has since been discontinued as the current efficiency was only about 30% with very irregular pitting of the anodes.

Subsequent experimentation, however, led the Gas Lines Department at Freeport to apply cathodic protection to 20 miles of 8-inch gas line between Freeport and Angleton, Texas, using 14-pound magnesium alloy anodes. This line was mechanically protected with coat tar enamel and 15-lb. felt, and had been in service three years before cathodic protection was applied. As a matter of convenience, the installations were made at gate-valve stations, sufficient anodes being installed at each location to give a minimum pipe-to-soil potential of one volt at that station. The number of anodes per station varied from 5 to 20, depending on the soil resistivity and pipe coating conditions in and around that particular location. All pertinent data are given on Fig. 1.

The anodes as installed on April 10-14, 1944, were spaced on 2-foot centers, 2 feet out from the pipe with top of anodes at pipe depth. Connection to the pipe was made through No. 4 insulated copper

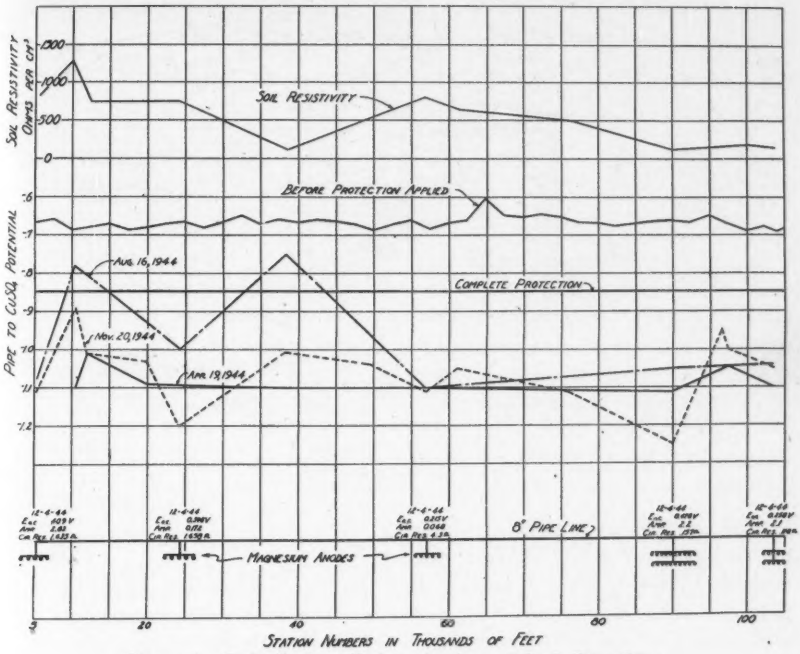


Figure 1—Cathodic Installation, Angleton 8-Inch Pipe Line.

wire, with a connection in the wire above ground so that an ammeter could be used to check the current output. These anodes were packed in sodium chloride.

Immediately after the installation of these anodes was completed, a pipe-to-soil potential survey was conducted to determine if additional anodes should be installed at intermediate points. It was found that the initial installation provided complete protection as evidenced by the potential curve for April 19th, Fig. 1. An explanation of the drop in protection on August 16th was due to a seasonal change in soil conditions, as the summer months were exceptionally dry. The initial current drain was 6.6 amperes and it had dropped to 4.82 amperes on November 26th, 1944.

The soil traversed by this pipe line is predominantly a heavy clay having a pH range of from 6.4 to 10.8 and a resistivity of from 50 to 1296 ohms/cm³ in place.

Current Efficiency Tests

March 2, 1944, a program was started to determine the effect of various electrolytes and fillers on the current efficiency of magnesium anodes when connected to a large non-polarizable structure. This structure was a 2330-foot long sea water flume made up of 14-foot lengths of bare steel piling. Limited

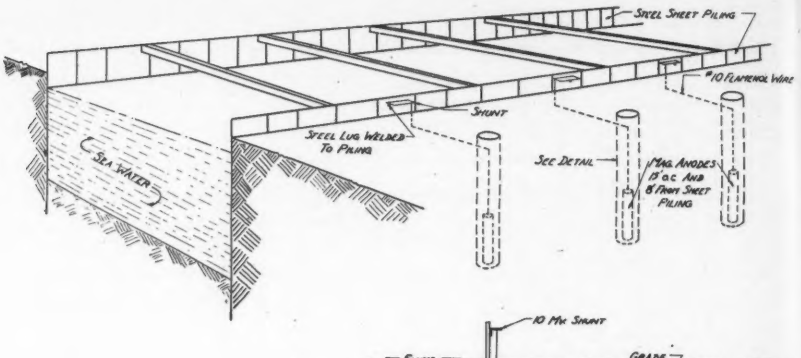


Figure 2. Experimental Installation at Sea Water Flume.

by the number of anodes available, six 14-lb. cylindrically shaped magnesium alloy anodes 4 inches in diameter by 18 inches long were buried in the soil and connected to the steel piling as shown in the diagrammatic sketch of Fig. 2.

Each anode was placed in a different electrolyte and the filler held in place by an ethyl cellulose bag. These bags were used to collect the products of corrosion for analysis. In correlating our work with that of the Physical Research Laboratory, three anodes were installed in electrolytes or fillers as listed in various reports from Midland, Michigan. Around each of the other three anodes, Aquagel (Sodium montmorrillonite, a bentonite clay) was used as a filler to which various electrolytes were added.

Aquagel was chosen as a preferred type of filler; first, because of its basic ion exchange properties, that is, its ability to replace the sodium ions with magnesium ions; second, because of its immense affinity for water; third, because of its enormous uniform surface of the order of 50,000 sq. cm. of surface per gram of material; fourth, the stability of this material, as it is formed by the weathering of volcanic ash.

The experimental data and examination of the individual anodes at the conclusion of the test indicate that Aquagel to a large degree gave the results anticipated as shown by Table I, although it should be noted that higher current densities may have contributed in part to the high efficiencies on anodes 4, 5, and 6.

Visual confirmation as to the action of Aquagel in controlling the corrosion of the anodes is shown in

TABLE I
Performance Data of Magnesium Anodes in Soil

Anode No.		Open Circuit Potential (Volts)	Average Circuit Resistance (Ohms)	Current Density Orig. Surf. (ma/sq.ft.)	Total Current Output (amp. hrs.)	Loss of Weight (grams)	Current Efficiency Percent
1.	25 # NaCl—1.7 # $Na_2Cr_2O_7$	0.761	0.888	526	3488	3791	41.7
2.	25 # Graphite—2 # $Na_2Cr_2O_7$	0.482	0.532	564	3737	3500	48.5
3.	25 # Graphite—10 # Na_2CO_3	0.465	0.832	502	3109	2725	51.8
4.	20 # Aquagel, Satr. Sol. NaCl, ½ # $Na_2Cr_2O_7$	0.783	0.661	853	5644	4722	54.2
5.	20 # Aquagel—15 # NaCl	0.785	0.821	798	5284	4364	54.9
6.	20 # Aquagel—0.2 # $Na_2Cr_2O_7$	0.680	0.531	805	4982	3390	66.7

the photograph, Fig. 3. Examination of this cross sectional view of anode No. 3 in Aquagel (bentonite) shows that the filler maintains a relatively homogenous mixture of magnesium salts around the anode. Another important factor is that the surface of all three anodes in this filler was practically free of any magnesium hydrate or oxide scale, whereas anodes in other electrolytes or fillers had much of their surface insulated by such scale. This latter factor is particularly important as evidenced by the type of corrosion experienced as shown in the photograph, Fig. 4. It can be seen that anodes Nos. 1, 2, and 3 experienced deep, irregular pitting due primarily to the setting up of local concentration cells between the clean and scaled surface, whereas anodes Nos. 4, 5, and 6 show a more uniform type of corrosion.

These six anodes were under test for a 6-month period, during which time an accurate record of the current output was obtained through use of a multipoint recording potentiometer connected across a 10-mv calibrated shunt in each circuit. A record of this output for each rod

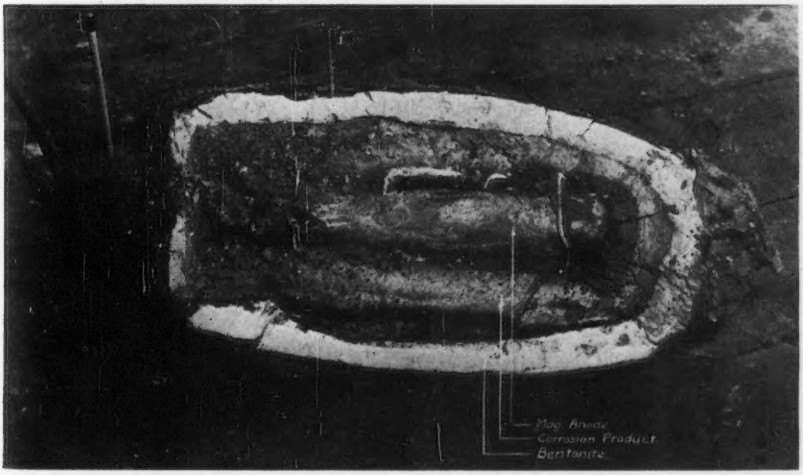


Figure 3. Cross Sectional View of Magnesium Anode in Bentonite. Anode Number 3.

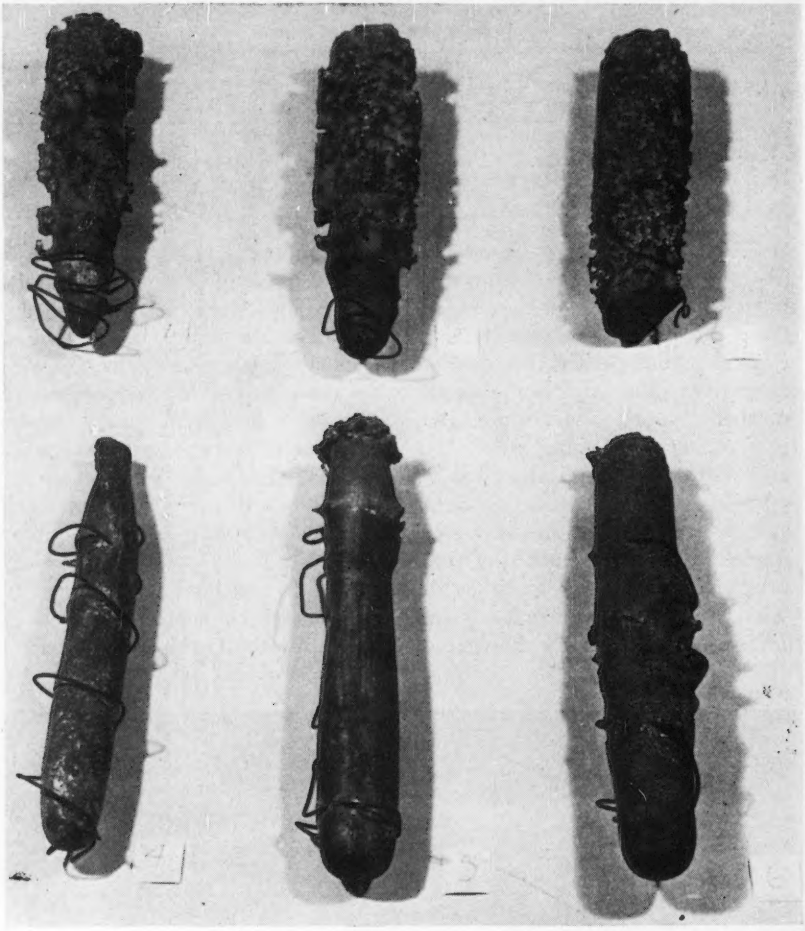


Figure 4. Types of Corrosion Experienced by Anodes.

is plotted on Fig. 5. The slopes of these curves prove that magnesium has little or no tendency to polarize under normal conditions and that the current output with time changes but little with decrease in anode surface area. This latter relationship is explained by the lowering of the resistance of the soil immediately around the anode tending toward a lower overall circuit resistance.

In addition to the current measurements, all tests pertinent to the performance of each anode were taken whenever possible (see Table II). To facilitate in the interpretation of these data, the method of

TABLE II
Measurement on Performance of Magnesium Anodes

1944	3–6	3–25	4–17	5–18	5–29	6–20	7–5	7–31	8–7	8–14	8–23	9–1
Rod No.						CURRENT OUTPUT IN AMPERES						
1	1.216	1.064	1.020	1.253	1.366	1.456	1.428	1.393	1.400	1.310	1.172	1.185
2	.856	.800	.742	1.013	.886	.903	.908	.846	.880	.814	.800	.828
3	1.512	1.228	1.113	1.140	1.177	1.273	1.220	1.200	1.146	1.107	1.020	.957
4	.736	1.109	1.030	1.185	1.157	1.261	1.250	1.327	1.292	1.172	1.167	1.280
5	1.168	1.080	1.126	.660	.625	.627	.615	.660	.660	.560	.686	.546
6	.720	.476	.596	.947	.977	.900	.927	.900	.885	.794	.890	.857
						CIRCUIT RESISTANCE IN OHMS						
1	.....	1.450	1.536	1.308	.942	1.100	1.716	1.064	1.122	1.152	1.240	.661*
2	.....	2.156	2.260	2.120	1.244	1.302	1.204	1.386	1.086	1.296	1.346	.532*
3	.....	1.500	1.432	1.564	1.248	1.158	1.190	1.170	1.098	.948	1.236	.821*
4	.....	1.212	1.386	1.302	1.316	1.168	1.116	1.048	.994	.976	1.146	.531*
5	.....	1.236	1.465	2.186	2.252	2.246	2.042	1.120	1.770	1.560	1.487	.852*
6	.....	2.128	2.452	1.700	1.482	1.624	1.842	1.794	1.496	1.294	1.418	.888*
						EO. C (OPEN CIRCUIT POTENTIAL IN VOLTS)						
1	.86	.82	.81	.82	.80	.81	.80	.80	.80	.82	.78	.7835*
2	.85	.78	.80	.58	.53	.55	.56	.58	.60	.62	.54	.4818*
3	.84	.80	.82	.77	.78	.76	.80	.79	.81	.78	.75	.7855*
4	.88	.81	.79	.84	.83	.81	.78	.81	.77	.82	.81	.6800*
5	.84	.80	.78	.60	.58	.66	.68	.66	.63	.65	.64	.4650*
6	.81	.80	.77	.76	.75	.75	.70	.74	.73	.72	.78	.7612*
						EO. C. MAG. ROD TO SOIL ($CuSO_4$)						
1	1.68	1.65	1.63	1.65	1.62	1.65	1.65	1.64	1.60	1.63	1.60	.....
2	1.62	1.59	1.51	1.42	1.35	1.43	1.42	1.50	1.45	1.50	1.35	.....
3	1.62	1.62	1.63	1.65	1.64	1.65	1.64	1.68	1.65	1.63	1.60	.....
4	1.65	1.62	1.60	1.69	1.67	1.70	1.63	1.66	1.61	1.60	1.60	.....
5	1.60	1.58	1.54	1.45	1.39	1.50	1.45	1.49	1.44	1.47	1.50	.....
6	1.65	1.57	1.55	1.61	1.58	1.61	1.61	1.64	1.61	1.64	1.65	.....
						ANODE TO SOIL POTENTIAL (CIRCUIT CLOSED)						
1	1.10	1.08	1.16	1.14	1.16	1.16	1.14	1.17	1.13	1.15	1.15	.93
2	1.15	1.16	1.10	1.02	1.10	1.07	1.05	1.09	1.16	1.20	1.25	.98
3	1.13	1.18	1.16	1.34	1.37	1.42	1.25	1.22	1.30	1.35	1.28	1.00
4	1.25	1.21	1.19	1.15	1.17	1.20	1.19	1.25	1.25	1.25	1.20	1.06
5	.97	1.02	1.04	1.08	1.01	1.09	1.05	1.04	1.01	1.05	1.15	.90
6	1.28	1.35	1.22	.98	1.10	1.03	1.05	1.11	1.05	1.25	1.20	.89
						FLUME—SOIL POTENTIAL ($CuSO_4$)						
1	.72	.80	.82	.86	.82	.92	.89	.89	.88	.88	.85	.87
2	.73	.80	.83	.88	.85	.90	.86	.87	.85	.90	.85	.85
3	.75	.81	.85	.88	.87	.94	.87	.93	.88	.90	.90	.89
4	.73	.81	.84	.86	.87	.91	.91	.95	.90	.95	.95	.96
5	.74	.77	.80	.82	.82	.87	.86	.88	.87	.90	.92	.90
6	.75	.77	.80	.80	.86	.89	.90	.90	.89	.95	.90	.90
						SOIL RESISTIVITY AT FLUME—Ohm/cm^3						
1	112	105	120	102	71	76	68	75	80	74	111	120
2	98	124	118	105	94	82	77	78	87	86	98	113
3	94	93	104	98	90	78	74	80	74	77	62	89
4	89	106	135	129	88	92	86	65	62	71	62	71
5	115	128	142	111	142	116	80	73	68	77	83	80
6	138	151	163	105	104	110	98	78	80	68	76	97
						SOIL RESISTIVITY AT MAG. ROD—Ohms/cm^3						
1	86	102	103	61	53	58	62	60	68	98	136	106
2	83	96	98	102	80	94	105	92	80	77	77	90
3	102	124	84	62	63	60	55	68	87	62	83	80
4	94	101	79	80	84	76	68	65	68	80	74	71
5	68	80	76	111	125	105	111	86	80	98	85	88
6	102	134	148	80	68	60	49	62	86	98	88	85

* Instantaneous open-circuit potential method.

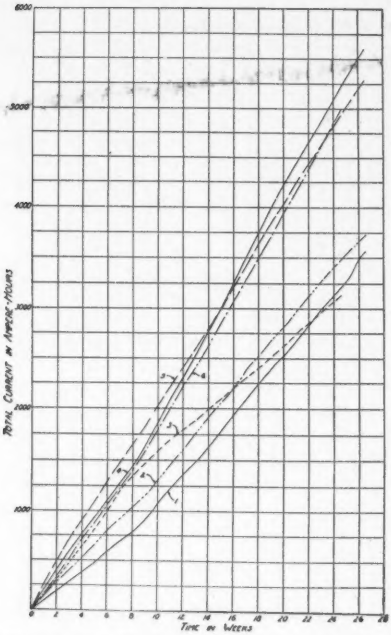


Figure 5. Performance of Magnesium Anodes for Six Month Period Ending September 3, 1944.

testing was as follows:

All potentials referred to a $CuSO_4$ electrode were taken with the electrode placed immediately adjacent to the structure under test through use of a 40-inch long salt bridge. (This bridge was a ¾-inch textolite rod with a ¼-inch hole extending lengthwise through the center, packed with asbestos and saturated KCl. The bottom end of this rod is sealed off with a wooden plug and the electrode screws in the top end.)

Up through August 23, 1944, the open circuit potential between the magnesium and the steel was measured with a vacuum tube voltmeter. Also, during this period, the circuit resistance was measured by inserting a calibrated potentiometer in the circuit and adjusting until the current flow was cut to one-half its original value. It was realized, however, that such tests were subject to error due to changes in polarization. A new method for such tests has since been devised and used since Sept. 1, 1944.

An instrument was designed to measure the open circuit potential by opening the circuit for approximately 1/100 of a second. This gives a close approximation of the effective driving potential of the circuit under actual operating conditions and by measuring current flow, the actual effective circuit resistance can be computed.

The anode design used in these initial tests, with a galvanized wire core cast in the magnesium, has been discontinued. The type of anode now used has a galvanized rod cast lengthwise through the center to within 4 inches of the bottom end.

The aforementioned sea water flume is of paramount importance to plant operation. However, at its present rate of corrosion the life of this structure is estimated to be about 5 years. As a means of prolonging its life to some 40 years, it was deemed necessary to apply cathodic protection. Comparison of the various methods of protection showed magnesium to be the low-

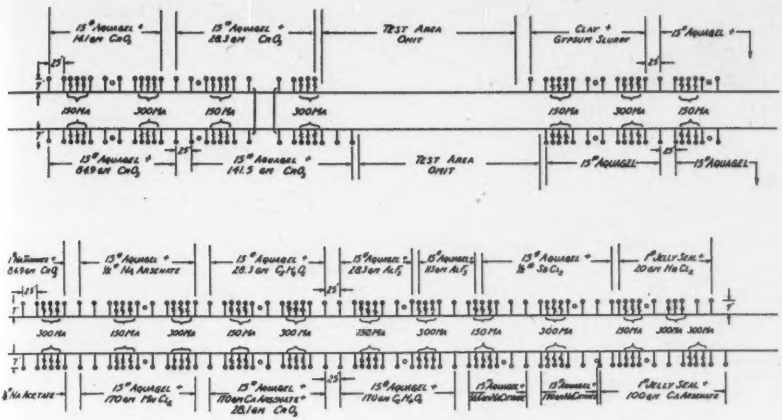


Figure 6. Experimental Magnesium Anode Installation for Sea Water Flume.

est in cost so it was used for this purpose. The anodes in this installation were of magnesium alloy 4 inches in diameter by 18 inches long and were installed as shown on Fig. 6. It is readily evident from this sketch that in addition to protecting this structure against corrosion by the sea water, tests on anode performance in different electrolytes and at varying current densities were also incorporated in the program. The potential from structure to sea water is 0.85 to 0.92 volts.

Selection of the various electrolytes received careful consideration and were chosen for one of three reasons; namely, results of laboratory experiments; known inhibitor for magnesium; or, recognized ability of raising hydrogen over-voltage on most metal surfaces.

As a further check on the effect of each electrolyte on magnesium, one anode was installed as a blank in each type of mix or backfill. These latter anodes are designated by the circles which are not connected to the steel piling. It is thought that these blanks may serve as a more accurate criterion in selection of proper backfill materials.

With each type backfill, resistors were installed to regulate the current drain from some of the anodes. This adjustment being such to give a current density of 100 and 200 ma per sq. ft. as shown in Fig. 6.

The schedule contemplated for this installation is based on a 6- to 12-month period, with the current output and circuit resistance of each anode to be checked biweekly and with all other tests pertinent to anode performance taken at two week intervals.

Magnesium Anodes

A special magnesium alloy has been developed that gives high current efficiency when used as an

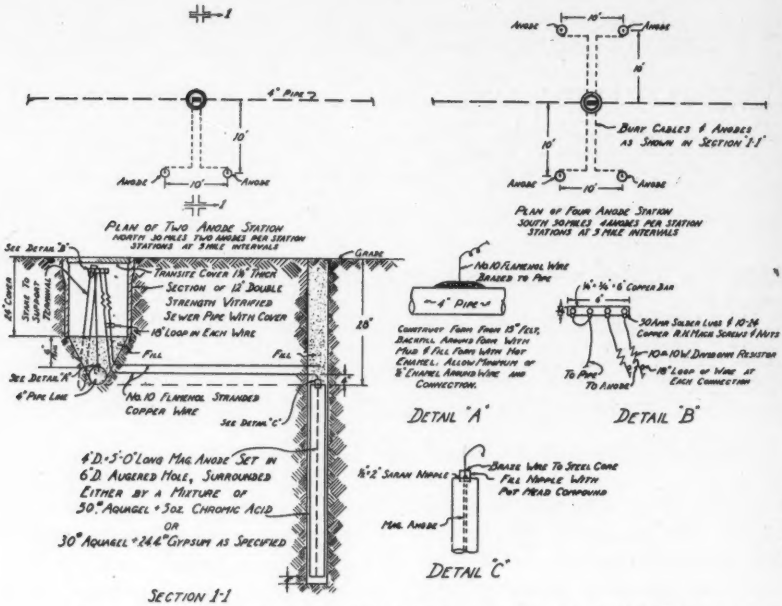

PLAN OF TWO ANODE STATION
PLAN OF FOUR ANODE STATION
SECTION 1-1
DETAIL "A"
DETAIL "B"
DETAIL "C"
GRADE
ANODE
FILL
4" PIPE
10'
18"
4'D.×5'-0" LONG MAG. ANODE SET IN 6'D. AUGERED HOLE, SURROUNDED EITHER BY A MIXTURE OF 50# AQUAGEL + 3 OZ. CHROMIC ACID OR 30# AQUAGEL + 24# GYPSUM AS SPECIFIED
TRANSITE COVER 1⅛" THICK
SECTION OF 12" DOUBLE STRENGTH VITRIFIED SEWER PIPE WITH COVER
18" LOOP IN EACH WIRE
No. 10 FLAMENOL STRANDED COPPER WIRE
BRAZE WIRE TO STEEL CORE
FILL NIPPLE WITH PIPE HEAD COMPOUND
MAG. ANODE
BURY CABLES & ANODES AS SHOWN IN SECTION 1-1
No. 10 FLAMENOL WIRE BRAZED TO PIPE
50 AMP SILVER LUGS & 10-24 COPPER R.H. MACH. SCREWS & NUTS
10 OHM 10 W DARESHANE RESISTOR
18" LOOP OF WIRE AT EACH CONNECTION

Figure 7. Typical Magnesium Anode Stations, Katy 4-Inch Pipe Line.

expendable anode. This alloy has the following composition limits:

Magnesium Alloy:	
Aluminum	5.3 to 6.7%
Manganese (minimum)	0.18%
Zinc	2.5 to 3.5%
Silicon (maximum)	0.3%
Copper (maximum)	0.05%
Nickel (maximum)	0.003%
Iron (maximum)	0.003%
Other impurities (maximum)	0.3%

Commercially pure magnesium gives approximately 0.1 volt higher solution potential, but it is more subject to local cell action and at low current will give lower current efficiencies.

A.S.T.M. Specification B-92-41 for Commercially Pure Magnesium Specifications

Total AL, Ca, Fe, Mm, M, Si	0.20% Max.
Cu	0.05% Max.
Ni	0.01% Max.
Mg (by difference)	99. 8% Max.

Selection of Backfills

Some of the most effective backfills to obtain high anode efficiency and anode life are as folows:

(1) For Low Resistance Soils
3 parts Aquagel
1 part ground Gypsum, Hydrated ($CaSO_4 . H_2O$)

(2) For High Resistance Soils
2 parts Aquagel
1 part ground Gypsum, Hydrated ($CaSO_4 . H_2O$)
1 part Anhydrous Sodium Sulphate

If an installation is made in acid soils (bog or peat marsh) or if commercially pure magnesium is used it is desirable to include one part magnesium hydroxide to the above backfill. This hydroxide raises the pH of the backfill and

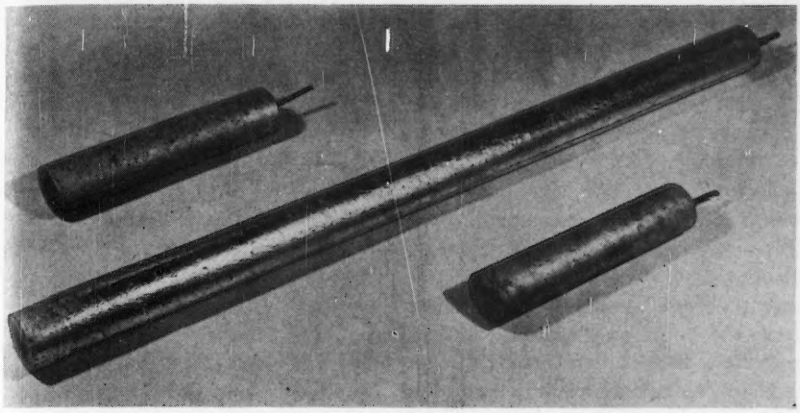


Figure 8. Some of the Anodes Used.

serves to reduce losses in efficiency due to acid attack and local action on commercially pure magnesium.

Cathodic Program at Freeport, Texas

The Dow Chemical Company in reviewing their needs for cathodic protection of their gas line system to Freeport, Texas, set up a program using the different types of backfill and anodes as previously outlined.

Briefly, this schedule calls for 29 magnesium anode stations on 185 miles of pipe lines with from 2 to 25 anodes per installation based on a minimum life of 10 years. A typical installation is shown in Fig. 7. At each station only one type of magnesium metal and backfill will be used.

Listed adjacent are comparative cost figures of different types of installations made in Freeport based on a 10 year life.

Rectifiers:	
Rectifier Unit (50 amperes output at 15 volts)	$ 317.00
Cable from Rectifier to structure and ground	125.00
Iron in ground bed at $20/ton	100.00
Installation	500.00
Current for 10 years at 4¢/KW, 50% Eff.	$5256.00
Maintenance $50/year	500.00
Service $30/year	300.00
Total cost of 50 amperes output for 10 years.	$7098.00
Cost of one ampere for 10 years	$ 141.96
Windchargers:	
Windcharger generator 2,000 watt output at 18 miles/hour (average output 25 amp.)	$ 651.00
50 foot tower for 125 miles/hour wind	307.00
Cable from generator to structure and ground	125.00
Iron in ground bed at $20/ton	50.00
Installation	484.00
Maintenance	868.00
Service	910.00
Total cost of 25 amperes output for 10 yrs.	$ 3394.00
Cost of one ampere for 10 years	$ 135.76
Gas Driven Generator:	
Gas driven generator average output 50 apms.	$ 865.00
Steel house	233.00
Iron in ground bed at $20/ton	100.00
Cable from generator to structure and ground.	125.00
Installation	768.00
Maintenance repairs	801.00
Service	2000.00
Gas, 4,380 Cu. Ft. @ 9¢	394.00
Oil 875 gallons @ 50¢	437.50
Total cost of 50 amperes for 10 years	$ 5723.70
Cost of one ampere for 10 years	$ 114.47
Magnesium anodes, 4 inches diameter, 60 inches long:	
4 magnesium anodes 50 lbs. each for 1 ampere in 10 years at 46.5% Eff. (Estimated cost 25¢/lb.)	$ 50.00
4 holes for anodes 6 inches by 8 feet	4.00
4 trenches 6 inches by 10 feet	4.00
Wire 80 feet No. 10, copper	.75
Connection to pipe	5.00
Chemicals in backfill	4.00
Cost of one ampere for 10 years	$ 67.75

Analysis of Data in Cathodic Protection of An Open Condenser Box

By J. J. Stadtherr

Resident Chemist, Heath Refinery, The Pure Oil Company

THE GREAT loss of metal by water-side corrosion and the resulting loss of operating capacity gives the petroleum industry ample reasons to be much concerned about up-to-date methods of controlling water corrosion of metallic equipment. Because of high temperatures and wide range of temperatures employed in a multiplicity of heating, condensing and cooling operations, refinery managements realize that there exists no one panacea capable of ending all corrosion problems.

Much has been accomplished by continued efforts to reduce corrosion rates in cooling water systems by making use of new alloys, by applying protective coatings, and by treating waters with chemicals.

Useful laboratory tests have been developed which predict, with limited accuracy, the scale-forming and corrosion tendencies of water. Several of the better known tests are recognized by the names "Carbonate Saturation Index" (1), "Langlier Index" (2), and "Stability Index" (3). Ample literature, available for study of chemical treating methods of combating corrosion, is voluminous (4, 5, 6, 7, 8, 9 & 10). Unfortunately, not much has been published about electrical or cathodic means of combating water corrosion, although fundamentally the problems are similar to those encountered in cathodic protection of pipe lines—a method which is widely used on pipe-line systems and which has been highly successful (11, 12, 13, 14, 15, 16, 17, 18, 19 & 20).

Galvanic corrosion control methods are based upon the knowledge that the more noble of the metals in the electromotive series are protected against corrosion at the expense of the less noble when two or more are connected and immersed in water.

This phenomenon was first observed and studied by the German physicist, Walter Nernst, and because of its relation to the natural tendency of metals to go into solution in water, Nernst's theory of "electrolytic solution pressure" is fundamental in the study of corrosion control by electrical means. There is a proportional relationship between this corrosion tendency of a metal and its electrolytic solution pressure. For instance, platinum, which is near the bottom of the electromotive force series and is highly resistant to corrosion, has an electrolytic solution pressure of only 1×10^{-36} atmospheres; while magnesium, near the top of the series, corrodes easily and has an electrolytic solution pressure of 1.1×10^{43} atmospheres.

It is generally quite well known that the corrosion of iron at normal temperatures will proceed very slowly, if at all, in the complete absence of moisture. Water is necessary to carry and supply the hydrogen which enters into the electrochemical reaction of corrosion represented in the following equation:

$$\underset{\text{Metal}}{Fe} + \underset{\text{Ions}}{2H^{++}} = \underset{\text{Ions}}{Fe^{++}} + \underset{\text{hydrogen}}{\text{Atomic } 2H}$$

In like manner any metal will displace another metal below it in the electromotive series.

With a system such as we have in an open condenser box, iron pipes immersed in water gradually go into solution because the water contains hydrogen ions, which, being below iron in the electromotive series, will be displaced by the metal in the pipes and walls of the condenser.

The electrolytic potential between coils and the water in a condenser box is influenced by a number of factors: 1, the composition of the metal; 2, the nature of the ions dissolved in the water; 3, the concentration of ions in the water; 4, the temperature; and 5, the pressure (21, 22).

Interesting experiments which demonstrate electrolytic and galvanic corrosion are described by B. B. Morton of International Nickel Company (23). For practical methods of measuring electrolytic potentials, and for practical application of the existing knowledge of the theory explained above, N. A. Miller of Universal Oil Products Company has prepared a valuable and useful reference (24).

Cathodic protection is a process of preventing corrosion which makes use of outside electrical current in reverse to that normally set up at the anodes as a result of natural electrolytic potential. This is done so that, by use of inexpensive auxiliary anodes made of scrap iron, the tubes and condenser walls can be made cathodic and thus be protected while the scrap iron anodes are consumed by the compensating "artificial" corrosion. Hydrogen plates out on the cathodic parts of the condenser surface tending to insulate it against further corrosion, but, unfortunately, the hydrogen film thus formed is disturbed or destroyed by 1, heat; 2, velocity of the water; 3, suspended solids; 4, oxygen, and 5, possible other reactive materials in the circulating water.

It would not be unreasonable to suppose that complete stoppage of corrosive action should follow the installation of a sufficient number of well distributed anodes supplied with sufficient electrical potential in the right direction. It should be realized, however, that because of the disturbing influences mentioned above, the problem is not quite that simple. The lack of comprehensive data concerning typical cathodic installations on open condensers is perhaps the chief reason for reluctance on the part of refiners generally to apply cathodic protection to open condensers. Several investigators in this field, including N. A. Miller (24), suggest the need for data from installations in refineries under typical operating conditions.

This paper was prepared in the

hope that data collected in connection with cathodic protection of an open condenser box at Heath Refinery of The Pure Oil Company, would, in part, supply this need for refinery data.

Discussion and Results

The condenser box to which cathodic protection was applied at Heath Refinery is known as "C" condenser box. Data descriptive of the box construction are tabulated in Table I. Analyses of the make-up water and water circulating within the refinery system are recorded in Table II.

TABLE 1
Heath Refinery Installation

Condenser Type	Open Box Type
Service	Straight Run Gasoline Condensing & Cooling
Approximate Size	47½"x34½"x10½" (inside)
Tube Size	Standard 4" Flanged Cast Iron 42 ft. long
Number of Tubes	90 South (section) 165 (North Section)
Sides & Bottom	Steel Sheet ¼"
Angles & Supports	Steel
Vapor (in) Temperature	300° F.
Condensed Vapor (out) Temp.	120° to 140° F.
Water in Temperature	(Seasonal) 60 to 90
Water out Temperature	(Seasonal) 140 to 160

The condenser box is divided forming two separate sections which we will refer to as the North Section and the South Section. Figure 1 is a schematic sketch showing approximate dimensions and location of cathodic equipment.

Figure 2 is a photographic view of a corner section of the box showing some construction details and the method of supporting anodes. Two rows of anodes are placed between three bundles of standard 4-inch cast iron flanged pipe, 42 feet long, connected with simplex return bends. Two additional rows of anodes are placed between the walls of the condenser and the outside bundles. The bundle next to the south wall consists of 36 lengths of 4-inch cast iron pipe, 42 feet long. Each of the other two bundles consists of 27 lengths of the same kind of pipe.

TABLE 2
Water Analyses

Source:— City of Newark, Ohio System Treated from Licking River, North Fork.

	Make-up Water	Circulating Water
Volume (average) to Refinery	250 GPM	4500 GPM
Volume (average) to Box	.....	250 GPM
"P" Alkalinity as $CaCO_3$	2.0 PPM	0.0 PPM
"M" Alkalinity as $CaCO_3$	29.0	180.0
Total Hardness as $CaCO_3$	90.0	135
Total Solids	204	796
Dissolved Solids	182	755
Suspended Solids	22	41
Chloride as Cl	11	33
Sulphates as SO_4	2	15
Calcium as Ca	33	56
Magnesium as Mg	10	13
Phosphates as PO_4	Trace	10
Oil	None	30
pH	9.0	7.3
Langlier Index at 80° F.	+0.60	+0.25
Langlier Index at 180° F.	+1.45	+1.05
Stability Index at 80° F.	7.8	7.3
Stability Index at 180° F.	6.21	5.7
Auxiliary Chemical Treatment	.....	Lime, Soda, Chlorine † Boiler blowdown containing phosphates

The box was put in service in 1930. During the early history of this box little trouble was experienced as a result of corrosion because, until 1938, a highly depositing well water was used for cooling. When, in 1938, the purchase of partially softened water from the city of Newark was begun, the coils and sides of the box were heavily scaled. In places the scale was as much as one-half inch thick. The city water from the South Fork of the Licking River was corrosive to a slight extent and was made more so by

forced-draft cooling. Within a year, corrosion was becoming a serious problem.

Corrosion was checked to a limited extent by controlling the nature of the water in line with the familiar calcium carbonate saturation test. Lime was added in sufficient quantities to maintain slight carbonate deposition. In December, 1939, three tubes corroded through, even though in some places scale was still very thick. Corrosion was severe at the water level and in May, 1940, it was necessary to renew header take-offs. Corrosion continued severe on areas not protected by carbonate scale. The carbonate scale was causing the sacrifice of much needed cooling, and, therefore, plans were made to try out cathodic treatment.

For the purpose of a preliminary trial, a welding generator was used as the source of direct current. Copper 2/0 conductor was used between the generator and the box. The anodes were made of scrap pipe 9 feet long, 1 inch and 4 inches in diameter. The original installation consisted of 35 anodes distributed over both North and South sections of the box. Twenty-one anodes were made of 4-inch discarded furnace tubes and 14 were made of 1 inch pipe.

With a current output of 60 amperes at 6 volts, it was possible to increase the potential of the cooling water 0.10 to 0.30 volt above that of the condenser coils.

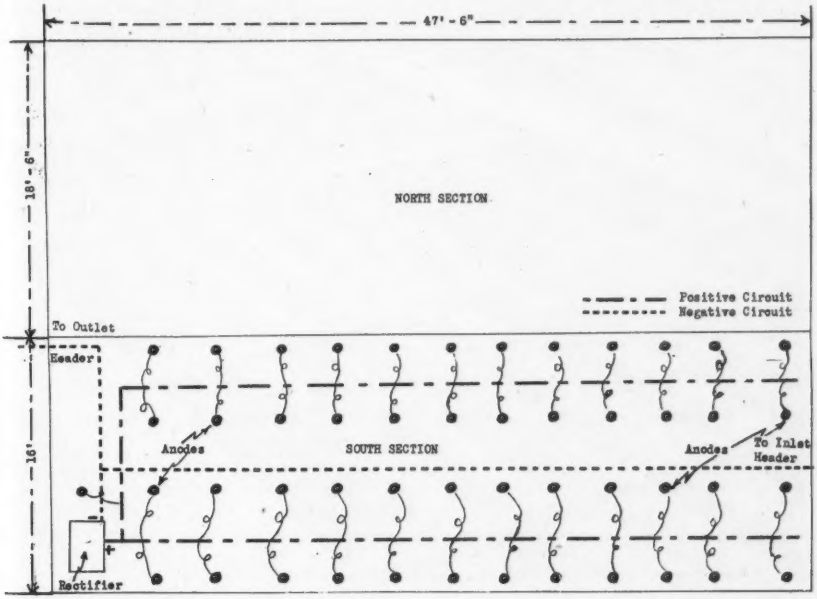


Figure 1—Schematic sketch of "C" condenser box, showing approximate dimensions and location of cathodic equipment.

Because of the necessity of using the welding machine from time to time, the cathodic protection during the trial period was intermittent. After two months operation, inspection failed to show beneficial results other than loosened scale. Bright corroded spots were numerous. However, it was observed that large chunks of carbonate scale had become dislodged and fallen away from tubes and side walls.

There was evidence that some time during the trial period the current had been inadvertently reversed. With the generator being taken on and off for welding purposes, the polarity could have easily been changed. The evidence was supported, in addition to lack of protection, by the following analysis of deposits taken from both the coils (cathodes) and anodes.

Scale Analysis

	Cathodes Percent	Anodes Percent
Iron and Aluminum	22.12	85.62
Calcium as $CaCO_3$	24.47	0.00
Magnesium as $MgCO_3$	19.71	0.00
Chlorides as NaCl	0.16	0.44
Silicious Matter	5.53	2.50

We would expect little or no iron oxide on the cathodes. Neither would we expect chlorides concentrated on the cathode. That these were present in appreciable quantities supports the belief that for a period the current had been reversed. The fact that neither calcium nor magnesium was present in the de-

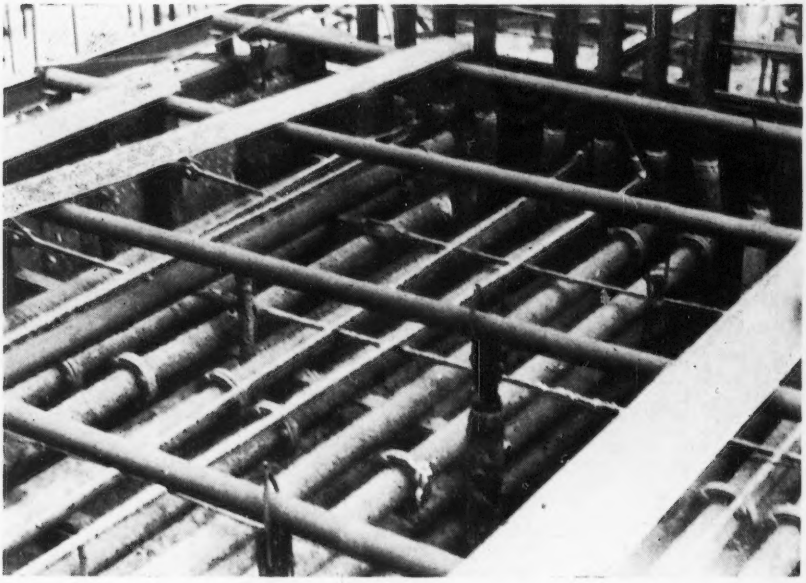


Figure 2—View showing construction of "C" condenser box and method of supporting anodes.

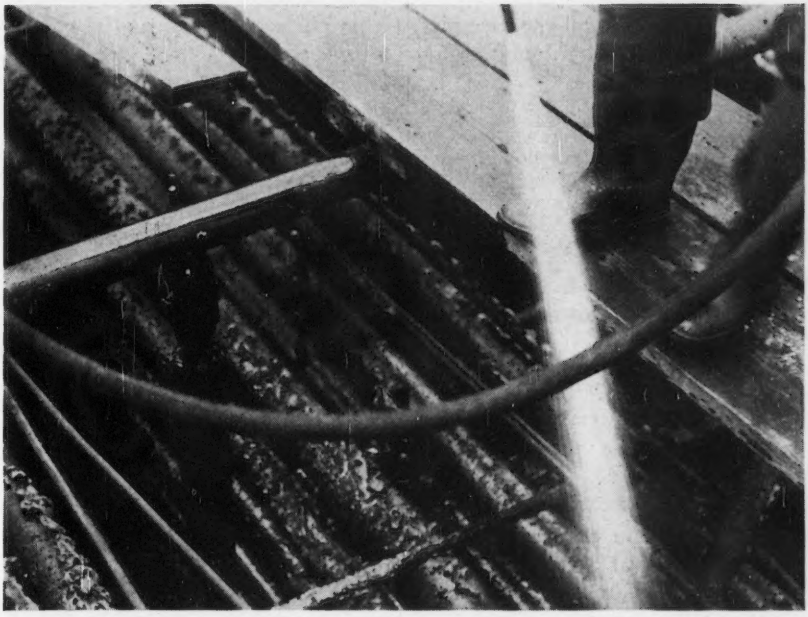


Figure 3—The loose, fluffy scale could easily be washed off by water pressure.

posit from the anodes can be explained by temperature differences. The anodes are relatively cold while the coil is hot, inducing carbonate and silicious deposition.

In November of 1941, after two months of cathodic protection, although general appearances were none too promising, corrosion strip data revealed a reduction in metal penetration. The 1-inch anodes were rapidly disintegrating and it was decided to increase the number to 41 and replace the 1-inch with 2-inch pipe and 12 2-inch carbon anodes. Two sections of cast iron coil were sandblasted for the purpose of better observation of results.

Due to difficulty in getting delivery of the necessary rectifier for a permanent installation, the welding generator was continued in service until April, 1942. However, in March, an inspection was made which revealed what appeared to be a much improved condition both as to corrosion and scale deposition. The corrosion was still in evidence, however, especially on the steel bottom. The scale deposition was limited to areas nearest to the anodes and scale was of a loose fluffy nature, easily washed off with water pressure, as shown in Figure 3. This soft scale did not interfere with efficient heat transfer to the extent experienced with the former dense scale.

In April of 1942, a permanent installation was made consisting of a 10 volt, 60 ampere, single phase, oil

immersed, Selenium Type Rectifier. The anodes were distributed as follows:

North Section:	
31	2" Standard Line Pipe
10	4" Furnace Tubes, .5" Wall
South Section:	
14	2" Standard Line Pipe
14	4" Furnace Tubes, .5" Wall
69 Total	
Exposed Area:	
North Section	11,477 sq. ft.
South Section	6,596 sq. ft.
Total	18,073 sq. ft.

$$\text{Current Density} = \frac{61.75 \times 1000}{18{,}073} = 3.42 \text{ milliamperes per sq.ft.}$$

Because of the fragile nature of carbon electrodes, difficulty in getting deliveries and added expense, only scrap iron electrodes were used.

There were no changes made in the system until December, 1942. However, in July, the carbonate scale on the coils was cleaned off with acid which had been inhibited against severe acid action on metal. Although corrosion was still noticeable on scattered areas, it was observed that the corroded spots were far removed from the nearest anode. The bottom corrosion was still severe and it was decided that better current distribution could be had if the lower ends of the anodes were connected. This was done using scrap 1-inch tie rods.

In July of 1943 it was decided to remove all protection to the South Section; see Figure 1. Forty-nine anodes were installed in this section. An average current of 56 amperes was used making the current density: $\frac{56 \times 1000}{6{,}596} = 8.49$ milliamperes per sq. ft.

During the subsequent operating period, advantage was taken of the splendid opportunity to compare corrosion test strips in the cathodic protected section with penetration

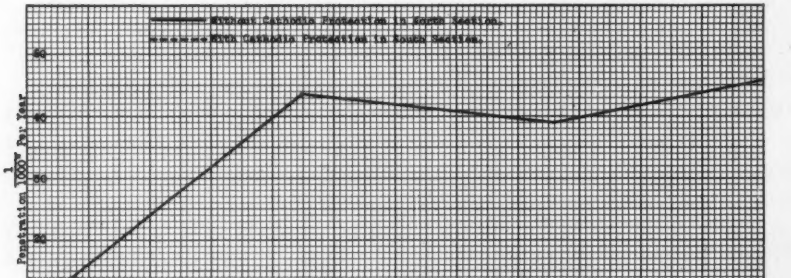


Figure 4—Penetration of cast-iron corrosion strips fastened to top coils of "C" condenser box.

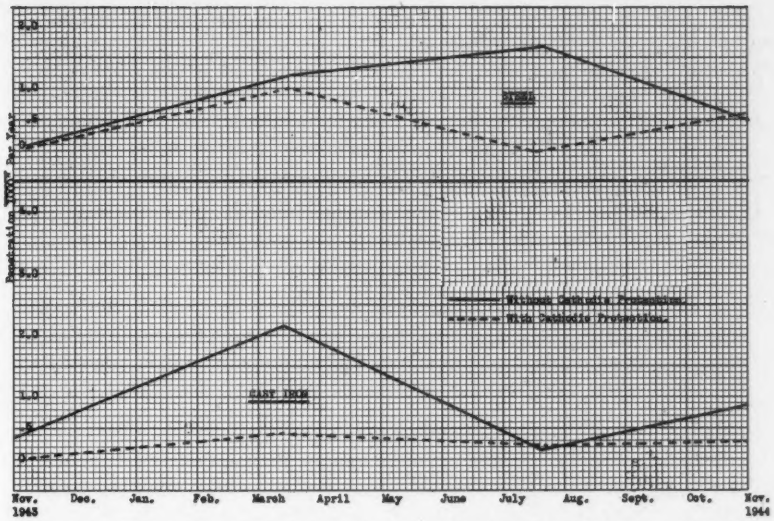


Figure 5—Penetration of steel and cast-iron corrosion strips fastened to bottom coils of "C" condenser box, South section.

of test strips in the unprotected section. A graph showing the penetration rates on cast iron in both sections through one year is shown in Figure 4. The penetration in the protected section was practically nil while that in the unprotected section was somewhat severe, approaching a maximum of 0.046" per year.

When these test coupons were placed, in July of 1943, they were installed in pairs. One of each pair was bolted to the flange of the cast iron tube, making an electrical connection. The other was installed about 8 inches away from the coil on an insulating holder made of transite, so that one would receive the benefits of cathodic protection and the other, on the insulating holder, would be isolated from such protection. Figure 5 is a graph showing the comparison of both steel and cast iron penetration. The coupons were fastened to the bottom coils of the South protected section. Figure 6 is a graph showing the penetration rate of steel coupons fastened to top coil. Figure 7 represents the penetration rate of steel coupons on the bottom coil. The solid line represents the rate in the unprotected North section and the broken line represents the rate of penetration in the cathodic protected South section.

Corrosion on the box bottom seemed always to be more severe than on the coils. This was thought to be due to the lack of sufficient anodic area adjacent to the bottom. To overcome this deficiency, a scrap steel plate 20 inches square was welded to each anode as shown in Figure 8. The low penetration as

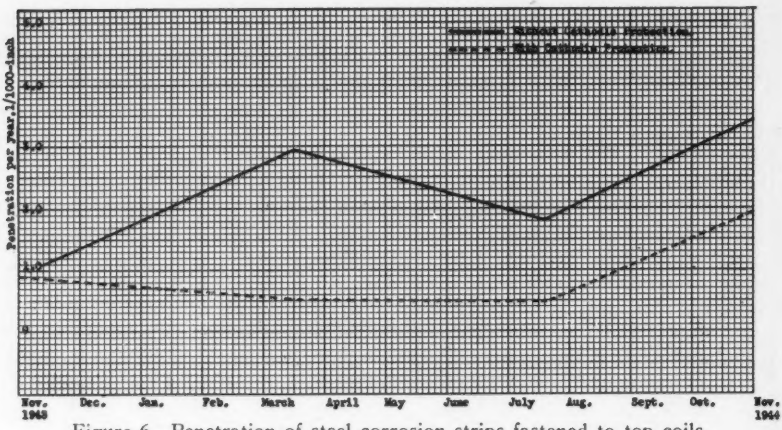


Figure 6—Penetration of steel corrosion strips fastened to top coils of "C" condenser box, South section.

indicated by the graph of Figure 9 reflects the benefits of this change in the anodes since the penetration as indicated by the corrosion strip data is comparable to that shown in Figure 7.

At best, corrosion strips are none too dependable; however, they are of limited value for indicating trends. The significant thing shown in these graphs is that some degree of protection is being realized. One wonders in studying these graphs why it is that the strips on the insulating holder do not show comparable penetration to the strips in the unprotected section of the box. A possible explanation is that even though they are fastened to an insulating holder, the insulating material is immersed in an electrolyte and some degree of protection is

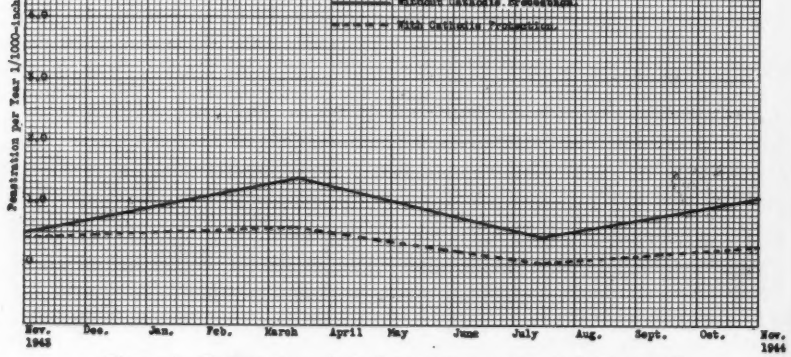


Figure 7—Penetration of steel corrosion strips on bottom coils of both North and South sections.

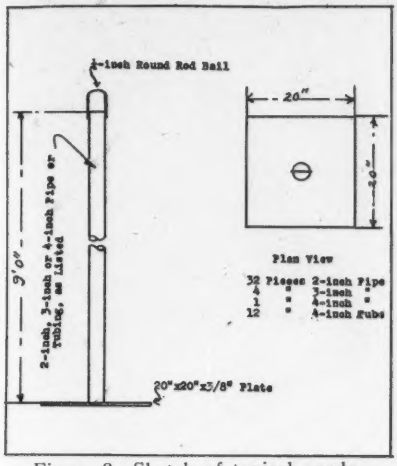


Figure 8—Sketch of typical anode.

realized because of leakage of current through the water-soaked insulation strip.

In June of 1943, chlorine was added to the circulated water to maintain a residual of 2 ppm. This resulted in a decreased pH value which increased corrosion rates until it was compensated for by the addition of soda ash.

Figure 10 is a close-up photograph of an anode which is covered with iron oxide "blisters." This deposit was dark red in color and analyzed 96.04% iron oxide. It will be observed that there are spots on the anode which are free of deposit. This particular anode is one of the old furnace tubes which was coated with a dense oxide scale. This oxide scale, it was thought, prevented the best current distribution. For that reason, on a subsequent cleaning, the dense scale from these anodes was removed. The following inspection revealed the deposit to be more evenly distributed on the anode as seen in Figure 11. This photograph shows, also, how the scale on the cathodes is affected by proximity to an anode.

Following are analyses of two dissimilar scales. The soft scale is from a point in close proximity to an anode. The hard, dense scale is from a point some two feet from the nearest anode.

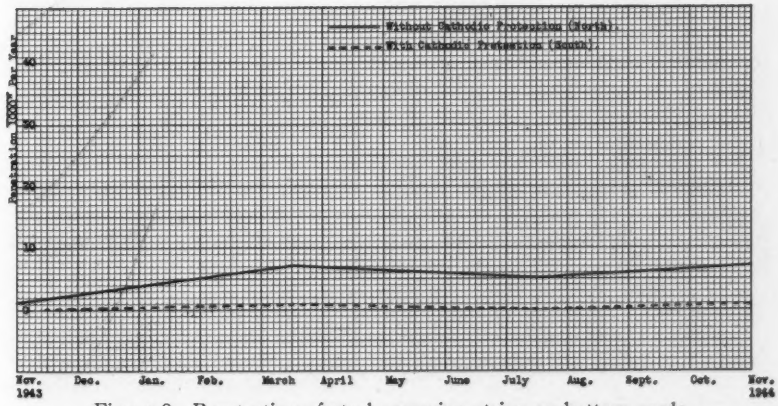


Figure 9—Penetration of steel corrosion strips on bottom angle of "C" condenser box, South section.

Scale Analysis—from Cathodes

	Soft Scale Percent	Dense Scale Percent
Oil	0.0	2.3
Moisture	1.9	3.4
Iron and Aluminum	3.8	18.6
Calcium as $CaCO_3$	9.5	31.8
Magnesium as $MgCO_3$	33.2	22.6
Siliceous Matter	0.5	18.3

The plating out of hydrogen on the surface of the cathode is probably responsible for the fluffy nature of the deposit in close proximity to the anodes. The density of the scale increases with increasing distance from the anode. Likewise, the chief product of corrosion, iron oxide, increases with increased distance from the anode.

Accurate data which would indicate the monetary savings realized by this cathodic protection installation are not available. Cost records

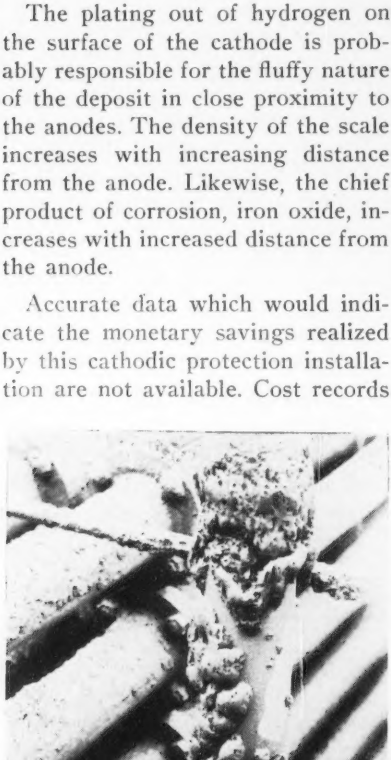


Figure 10—Close-up photograph of anode containing a deposit high in iron oxide.

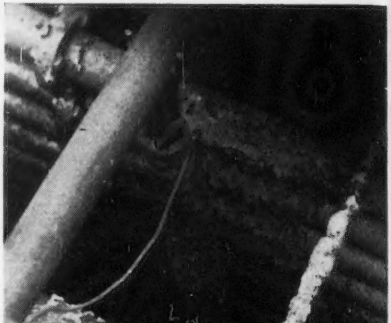


Figure 11—Scale on anode is distribu over the entire surface. Note nature cathode scale in proximity to anode.

from 1930 to 1939 are of no value because a radically different water was being used for cooling during this time. However, the tube and header take-off replacement costs during the year prior to cathodic protection were in excess of annual cathodic protection costs by approximately $50.00. Had the installation not been made, on-the-spot observers estimate that replacements in subsequent years might have well been several times the annual cost of cathodic protection. During four years of cathodic protection there have been no condenser tube failures. Therefore, expensive shut-down periods have been avoided which is far more significant than the costs involved in replacing corroded metal.

An installation such as described

above can be made at a cost of approximately $750.00. Cost of maintaining the unit, replacing anodes, repairs, etc., will approximate $125.00 per year. Power costs at $0.01 per kilowatt hour would be approximately $80.00 per year, provided the rectifier is held to its capacity of 60 amperes and 10 volts. The rectifier is rated 65 per cent efficient. However, in the case of the Heath Refinery Unit, an average of only 3 volts is required to maintain 56 to 60 amperes current flow. Therefore, the current cost is approximately $25.00 per year. With amortization of the original cost in five years the total annual cost of cathodic protection would be approximately as follows:

Amortization	$150.00
Maintenance	125.00
Power	25.00
Total	$300.00 = $25.00 per month

The best estimate from reputable water condition services estimate the cost of treating Heath Refinery water to eliminate scale and corrosion at about $92.50 per million gallons of make-up. The water through "C" condenser box is now costing for cathodic treatment plus auxiliary treatment about $47.00 per million gallons of make-up. However, the difference of $45.50 per million gallons of make-up should not be considered entirely as savings, because by chemical treatment of the entire circulating system at $92.50 per million gallons of make-up, certain advantages could be expected in all parts of the refinery. It is questionable whether these benefits would equal in value the difference between $92.50 and $47.00 per million gallons of make-up. It is also questionable if the more expensive water treating would reduce corrosion in "C" box as well as cathodic protection has up to this time.

Conclusions

In reviewing possible methods of combating water-side corrosion, refineries should consider cathodic protection as a valuable supplement to other methods such as the selection of equipment made of corrosion resisting alloys, chemical treating, and the application of protective coatings to equipment exposed to corrosive water. Certain explosion hazards inherent with electrical equipment, confined water-circulating spaces, and other limiting factors preclude the complete substitution of cathodic for chemical protection.

The complete distribution of cathodic protection on each square foot of box and coil is impossible. However, with careful distribution of anodic area, the ultimate service factor can be sufficiently improved to justify certain cathodic installations. To realize best results, it is necessary that certain areas have over-protection, in order that other remote areas receive a minimum degree of protection. This means that current density has to be somewhat higher than is actually necessary to protect. If too little current density is applied, remote areas may be entirely unprotected resulting in no improvement whatever in ultimate service factor. Failure to recognize

this can and perhaps has resulted in discouraging results with cathodic protection.

Iron plates or grids suspended between vertical rows of tubes would provide much improved current distribution. Current costs would be less but installation cost would be increased.

Data based entirely upon corrosion strips can be misleading since they are highly susceptible to error. Periodic inspections as well as good service records support the general conclusions suggested by the data reported above. No condenser tube failures in four years, very little corrosion on sides and bottom of the protected section, easily removed scale formations, plus encouraging corrosion strip data are evidence that cathodic protection of open condenser boxes merits continued use and study, and wider application in refinery corrosion problems.

Acknowledgment

The writer acknowledges the helpful assistance of his associates, Messrs. Harry Hook, General Operating Foreman; E. J. Deardurff, Assistant General Operating Foreman; C. P. O'Connell, Plant Inspector; and Carl F. Dildine, Laboratory Photographer.

The cover illustration, showing a destroyer in drydock, is an official U. S. Navy Photograph and is reproduced through the courtesy of the United States Navy. At the same time the destroyer is refitted after battle damage, the hull is scraped and painted in the Navy's unremitting struggle against corrosion damage to its floating equipment.

The Role of the Straight Chromium Stainless Steels for Vessel Linings in the Refinery Field

By W. J. Jackel

Assistant Director of Metallurgical Research, A. O. Smith Corporation

THE STRAIGHT chromium steels have enjoyed an important participation in combating corrosion in refinery processes and it is the purpose of this paper to trace the role of this group of stainless steels as they have been employed for refinery vessel linings. The 14 to 18% chromium steels, their embrittling characteristics at certain temperatures which militated against their use in certain services, will be discussed. Included is a discussion of the 11 to 13% chromium grades which became known. Hardening characteristics together with laboratory and field corrosion test data will be presented on the 11 to 13% chromium grades together with the same information on a modified 11 to 13% chromium grade to which has been added 0.25% aluminum to prevent air hardening.

It was prior to World War I in 1912 that the straight chromium steels were discovered by Brearley in England, the result of a search for a steel which would not foul in gun-barrel service. Brearley's steel contained 12.8% chromium, 0.24% carbon. It developed that the arms manufacturers were not interested, so Brearley approached the R. F. Mosley Cutlery Company. The success of the alloy is testified to by the result that this analysis with a slight increase in chromium (13.5%) and carbon (0.35%) became known as the "Cutlery stainless steel."

Commercial production of this grade started in 1914 in England and in 1915 in this country. However, it was not until 1920 that commercial quantities of the low carbon 12% chromium grade were made.

Mr. F. M. Becket of this country is responsible for the development

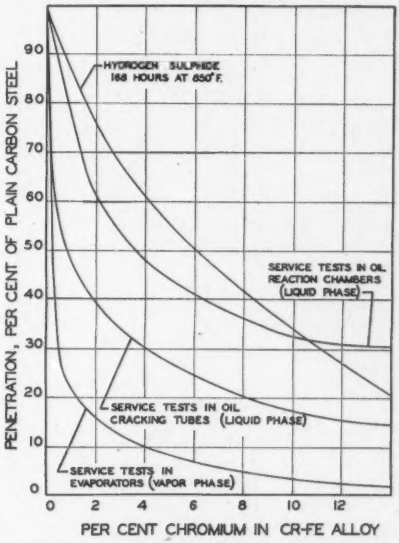


Figure 1—Effect of chromium on reducing corrosion under various conditions of operation. (From E. C. Wright's Chapter, "The Book of Stainless Steels.")

of the higher chromium steels, those approaching 20% chromium and above. Strauss and Mauer's work in Germany resulted in the patenting in 1912 by Krupp of a martensitic group of stainless steels (0.15% carbon, 14.0% chromium, 1.8% nickel) and an austenitic group of stainless steels (0.25% carbon, 20.0% chromium, 7.0% nickel).

The use of a straight chromium steel as a corrosion resistant lining for refinery vessels became popular about 1930. At that time the 14 to 18% chromium grade was favored for the reason that it had been established that increasing amounts of chromium effected increased resistance to sulphide corrosion at temperatures of 500° F. and above. This is demonstrated by the familiar set of curves of Figure 1. Sulphur, present in varying amounts in all crudes, joins with hydrogen released in the distillation or cracking of the crude to form hydrogen sulphide, an active corrodant in "distillation" and "cracking" processes.

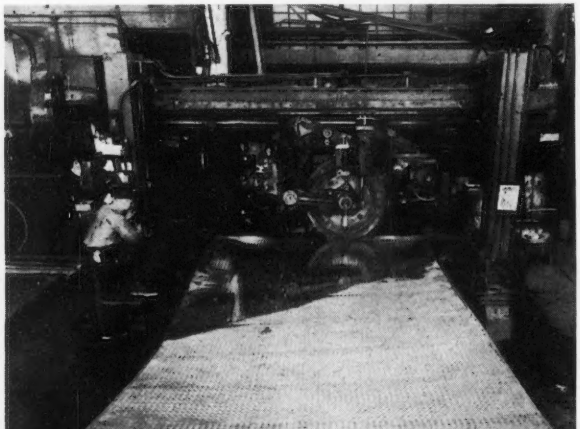


Figure 2—Spot welding of protective alloy lining to carbon steel plates which are then formed into shells, heads and nozzles.

14 to 18% Chromium—AI and SI Type 430

A chromium content of 17% was the usual aim in the above 14 to 18% range. The selection of the 17% chromium composition for service where corrosion from hydrogen sulphide was a consideration was justified by reason of the projected position of this analysis on the curves shown in Figure 1. Among the applications of the 17% chromium analysis for refinery protection, records show that about 50 vessels were lined by the A. O. Smith spot-welding process and were supplied to refineries throughout the United States and foreign countries. Figure 2 shows how the alloy lin-

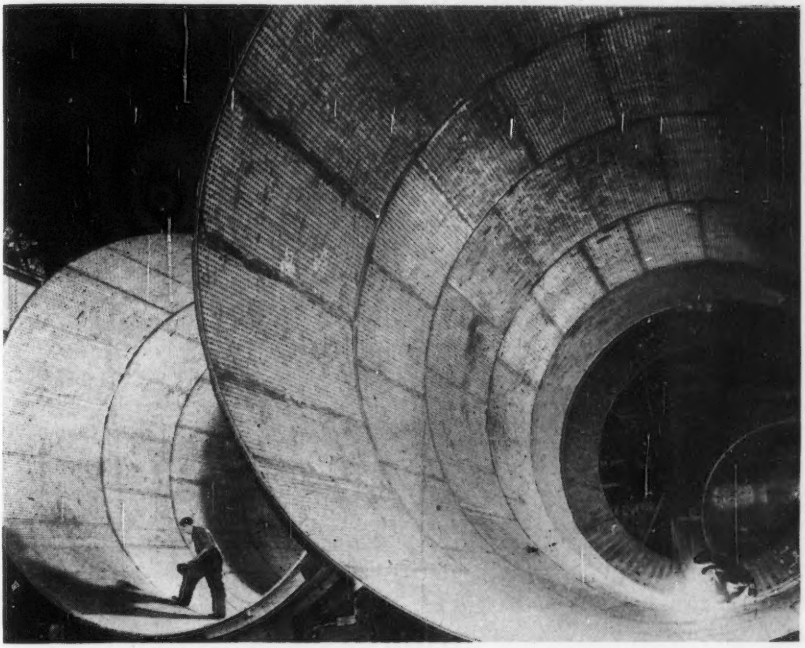


Figure 3—Vessel shell sections with spot welded linings.

ing is first spot-welded to flat carbon steel plates which are subsequently fabricated into vessel sections such as shown in Figure 3. With this process it is also possible to achieve protection for the strength-carrying unalloyed steel of the vessel shell and head sections with most of the austenitic stainless steels and a number of the high alloy non-ferrous materials.

An unforeseen characteristic of the 17% chromium alloy contributed to its early abandonment as a vessel lining where elevated temperatures were involved. This was in the form of an embrittlement or "ageing" which occurred after exposure for an extended period in the 750 to 950° F. temperature range. Associated with the embrittlement was an increase in hardness, both of which conditions were manifested in the alloy upon cooling to room temperature after exposure in the sensitive range.

Figure 4 illustrates the results of exposure tests in a laboratory furnace at temperatures within the dangerous range of 750 to 950° F. for a 16.96% chromium composition. Greatest hardening occurred at 850° F. After 2200 hours at 850° F. the hardness increased from Rockwell 86b to 100b. Alloy of similar composition after embrittling to the

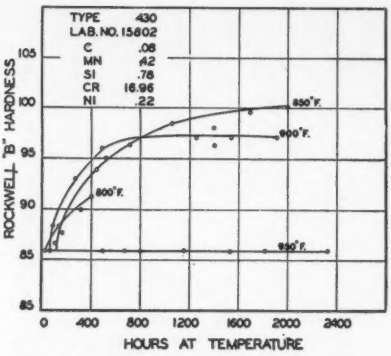


Figure 4—Hardness versus time at temperatures within the precipitation hardening range for Type 430, 17% chromium composition.

extent that cracking occurred in service, upon removal and checking hardness, showed 103b. In this instance the reported service was 5422 hours at 900-950° F. in a reaction chamber. An increase of hardness from Rockwell 67b to 85b has been reported on a 17% chromium composition after 14855 hours at 675° F.

11 to 13% Chromium—AI and SI Type 410

Failure of 17% chromium linings in refinery vessels prompted the selection of a composition which would operate at the high temperatures without becoming embrittled and at the same time afford comparable protection. The 11 to 13% chromium composition or original Cutlery stainless grade modified to contain a maximum of .15% carbon was selected and has since been widely used.

The 11 to 13% chromium grade was adaptable for vessel linings for, among others, these reasons: 1, ease of forming in the annealed condition; 2, similar coefficient of expansion as carbon steel; 3, not subject to rapid grain coarsening at hot-working temperatures with an attendant embrittlement in the manner of the 17% chromium grade; and 4, lower cost than the 17% chromium grade. One disadvantage of the lower chromium grade is a more intense air-hardening characteristic than the 17% chromium grade. For this reason greater precaution is necessary in welding the more intensely air-hardening grades of steel with provisions necessary for stress relieving after welding and annealing after hot-working. To understand the variable air-hardening characteristics of the two grades it is necessary to refer to the constitutional diagram for the chromium steels shown in Figure 5. The 11 to 13% chromium composition falls

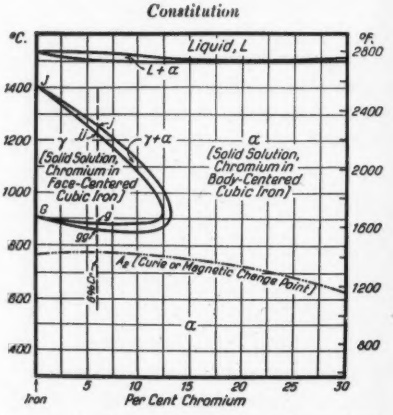


Figure 5—Iron end of the binary iron-chromium diagram. Carbon-free alloys containing more than 13% chromium can not be appreciably hardened by heat treatment. (From V. N. Krivibok's Chapter, "The Book of Stainless Steels.")

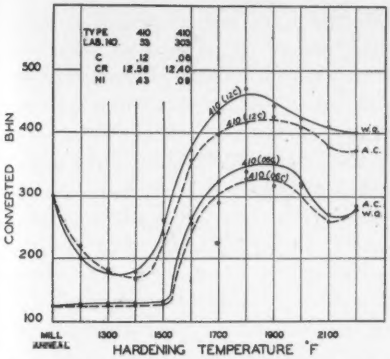


Figure 6—Comparison of the hardening characteristics after an air cool (A.C.) and water quench (W.Q.) of Type 410 and 430 compositions.

within the confines of the "Gamma Loop" whereas a 17% chromium alloy does not. Upon cooling a composition through the gamma loop, a gamma or austenitic phase is formed which, upon transforming to the stable alpha phase, forms a sufficient quantity of the hard martensite constituent to occasion a general hardening.

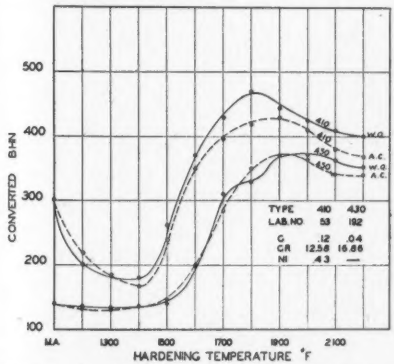


Figure 7—Comparison of the hardening characteristics after an air cool (A.C.) and water quench (W.Q.) of two Type 410 compositions with 0.12% and 0.06% carbon respectively.

On Figure 6, hardness data have been plotted to show a comparison of the hardening characteristics of 12.58% chromium and 16.86% chromium grades respectively. Duplicate specimens of each alloy were heated to temperatures from 1200° F. to 2200° F. at 100° F. intervals, one specimen was water quenched and the other air cooled, hardness determinations made and plotted as shown.

In view of the hardening power of the 11 to 13% chromium composition with carbon up to 0.12%, lower carbon compositions came into the picture and have since been popular for the reason of their lesser hardening tendencies, a feature highly desirable when welding is involved. A popular composition contains .08% maximum carbon. Figure 7 illustrates the lesser air-hardening properties of a .06% carbon material.

11 to 13% Chromium-Aluminum—AI and SI Type 405

The 0.08 maximum carbon 11 to 13% chromium grade was a decided improvement over the compositions with 0.12% carbon. Where extensive welding is employed such as on the lining for a pressure vessel, an analysis with a similar amount of chromium, but with an addition of 0.20 to 0.30% aluminum has shown further advantage for the reason of its lesser air-hardening characteristics. This composition under the AI and SI Type 405 classification has the following chemistry:

Carbon	.08 Maximum
Manganese	1.00 Maximum
Silicon	1.00 Maximum
Chromium	11.5 to 13.5
Aluminum	.10 to .30

Our preference favors a maximum of 13.0% for the chromium and 0.20 to 0.30% for the aluminum. A comparison of the hardening characteristics of the aluminum-bearing grade with the 0.08% maximum carbon Type 410 is shown on Figure 8. To explain the influence

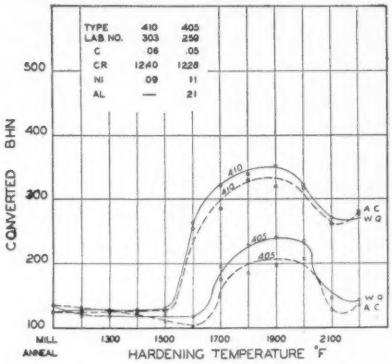


Figure 8— Comparison of the hardening characteristics after an air cool (A.C.) and water quench (W.Q.) of a Type 410 with 0.06% carbon and a Type 405.

of the aluminum it is necessary to refer to the gamma loop diagram, Figure 5. The aluminum moves the gamma loop to the left of the diagram so that upon heating to a temperature such as 1800° F. only about 40% of the alloy is transformed to the gamma or hardenable phase, whereas at 1800° F. without the aluminum the condition is all gamma. An additional effect of the aluminum is to raise the temperature at which transformation to the gamma phase occurs.

It has been mentioned that the advantage of the compositions with the lesser hardening characteristics manifests itself mainly in welding. Figure 9 illustrates this by showing the results of hardness traverses made on three welds typical of that employed to seal adjacent sections of alloy lining in a pressure vessel. An identical procedure was employed on all three welds which in this case included depositing a 25 Cr - 12 Ni seal weld with a 3/16-inch electrode. The thickness of the liner was 7/64-inch for the Types 405 and 410 (0.06 carbon) and 3/32-inch for the Type 410 (0.12 carbon). The Rockwell A scale was used to make the hardness traverse and converted to Brinell hardness for plotting.

Mention has been made earlier that the 12% chromium group of alloys was not susceptible to "ageing" or embrittlement in the 750° to 950° F. temperature range. Many thousands of hours of successful service in vessels in operation for over eight years for the Type 410 and over four years for the Type 405 have been the experience. On Figure 10 are included data to show the results of hardness studies made on typical Type 410 and 405 analyses after extended exposure periods in the laboratory. These and other studies have shown that the 12% chromium alloys are not susceptible to embrittlement providing the chromium content does not exceed 13.0%. A comprehensive investigation of the embrittling or hardening susceptibility of the straight chro-

TABLE I

Physical Test Data on Straight Chromium Alloys After 1050 Hours Exposure at 800° F.

C	Cr	Ni	Al	Yield Point psi	Ultimate Strength psi	Elongation in 2" Percent	Reduction of Area Percent	Rockwell Hardness	Keyhole Charpy Impact Ft., Lbs.
.15	16.7	.23	.03	75600	117200	25.5	42.3	B96	32.2
		After Exposure.....		102200	136000	26.0	37.3	B101	10.7
		Percent Change.....		+26	+13.8	+1.9	—11.7	+5.5	—66.8
.04	17.0	.24	.018	66150	98050	30.5	49.0	B84	48.8
		After Exposure.....		105000	124100	25.2	41.5	B96	3.5
		Percent Change.....		+37	+20.1	—17.2	—15.4	+15.3	—93.3
.12	11.6	.14	.039	88200	118000	23.75	43.3	B94.5	42
		After Exposure.....		94600	121950	23.75	40.5	B95.0	37
		Percent Change.....		+7.2	+3.35	.....	—6.58	+ .53	—11.9
.05	11.7	.15	.041	64700	98266	30.3	48.5	B79	48
		After Exposure.....		58250	96150	34.2	48.8	B81	43
		Percent Change.....		—9.97	—2.16	+11.5	+ .6	+2.5	—12
.07	11.6	.06	.21	60500	90750	33.0	54.0	B81.8	51.2
		After Exposure.....		56100	92650	33.5	49.9	B81.7	54
		Percent Change.....		—7.28	+2.0	+1.5	—7.6	.....	+5.1
.06	12.0	.06	.40	54500	86400	34.2	46.7	B95.8	44.5
		After Exposure.....		58000	87900	33.5	50.5	B95.2	47.0
		Percent Change.....		+6.03	+1.79	—.22	+7.6	.....	+5.3

mium grades was made upon request to one of the steel suppliers. The results of complete physical tests made before and after an ageing treatment on six analyses from experimental induction furnace heats are shown in Table I.

Corrosion Aspects

As previously mentioned alloys containing increasing amounts of chromium are favored for resisting sulphide corrosion at temperatures above 500° F. Over 100 vessels Smith-lined with either Type 405 or 410 have given satisfactory service, handling some of the most corrosive crudes in reaction, flash and coke chambers, and in separator services where operating temperatures range from 800° F. to 950° F., with about the same number in bubble tower, fractionator and exchanger shell services where temperatures between 500° F. and 750° F. are involved. At temperatures below 500° F., frequently found at the top of some towers, weak acids, such as hydrochloric, form if the crude is salty. Under these conditions the straight chromium grades will be actively attacked making it necessary to go to the other alloys for protection.

Some comparative corrosion data have been accumulated on the various alloys from exposure tests in operating equipment. Listed in Table II are corrosion data on seven alloys which were exposed for 6250 hours in three locations of a crude stabilizer tower and in one location in a separator tower. The results of this exposure program showed that the performance of the 12% chromium alloys compared very favorably with the 17% chromium alloy on the basis of both penetration rates and susceptibility to pitting attack. As would be expected, the

TABLE II

Corrosion Rates and Pitting Characteristics on Typical Alloy Lining Materials Exposed 6250 Hours in Refinery Service

	CRUDE STABILIZER												SEPARATOR TOWER			
	Set 0—Above Tray 1 H_2S–150° F. 100 Lb.				Set 1—Below Tray 15 Gasoline–325° F. 105 Lb.				Set 2—Above Tray 16 Vapor 375° F. 95 Lb.				Set 3—Above Tray 1 Vapor 690° F. 390 Lb.			
	X-Weld		Stress		X-Weld		Stress		X-Weld		Stress		X-Weld		Stress	
Alloy Material	Pen. In./Yr.	Max. Pit	Pen. In./Yr.	Max. Pit	Pen. In./Yr.	Max. Pit	Pen. In./Yr.	Max. Pit	Pen. In./Yr.	Max. Pit	Pen. In./Yr.	Max. Pit	Pen. In./Yr.	Max. Pit	Pen. In./Yr.	Max. Pit
4-6 Cr	.0043	.01	.0059	.01	....	....	....	....	....	....	....	....	....	....	....	....
12 Cr	.0020	.03	.0024	.02	.0342	.02	.0054	.01	.0338	.03	.0049	.01	.0063	.01	.0089	nil
12 Cr+Al	.0017	.05	.0032	.01	.0036	.03	.0042	.025	.0348	.02	.0055	.025	....	....	....	....
16 Cr	.0023	.02	.0039	.03	.0041	.03	.0053	.05	.0015	.025	.0099	.025	.0011	.01	.0020	.025
18 Cr-8 Ni	.0009	.025	.0015	.015	.0010	.03	.0015	.03	.0048	.025	.0050	.03	....	....	....	....
18 Cr-8 Ni+Cb	.0006	.025	.0011	.02	.0008	.04	.0014	.02	.0115	.01	.0115	.01	.0004	.01	.0007	.01
18 Cr-8 Ni+Mo	.0001	.03	.0003	.01	.0002	.02	.0004	.03	.0123	.03	.0106	.01	.0003	.04	.0005	.025

GRADE	Lab. No.	C	Mn	Si	Cr	Ni	Other
4-6 Cr	51	.06	....	....	4.92	.13	.....
12 Cr	53	.12	....	....	12.58	.43	.....
12 Cr + Al	54	.07	....	....	13.44	.28	.27 Al.
16 Cr	60	.08	.41	.45	17.01	.12	.....
18 Cr–8 Ni	7191	.05	.45	.28	19.19	8.95	.....
18 Cr–8 Ni + Cb	120	.08	.33	.36	18.53	10.40	.75 Cb.
18 Cr–8 Ni + Mo	121	.07	1.39	.33	17.43	12.76	2.79 Mo.

TABLE III

Laboratory Corrosion Tests on Straight Chromium Alloys 65% Boiling Nitric Acid—200 CC./SQ. Inch

Mill Annealed

				INCHES PENETRATION PER YEAR			
C	Cr	Ni	Other	1st Per	2nd Per	3rd Per	Average
.12	12.0	.28	.....	.822	.715	.808	.782
.09	12.3	.33	.46 Mo.	.228	.228	.169	.208
.07	13.4	.28	.27 Al.	.090	.100	.100	.097
.06	12.7	....	.50 Cb.	.311	.462	.428	.400
.08	17.0	.12	.....	.030	.031	.047	.036
			Heated to 1200° F.—2 Hours at Heat Furnace Cooled to 900° F.—Then Cooled in Air				
.12	12.0	.28	.....	.473	.413	.431	.439
.09	12.3	.33	.46 Mo.	.183	.181	.65	.176
.07	13.4	.28	.27 Al.	.095	.098	.090	.094
.06	12.7	....	.50 Cb.	.246	.262	.277	.262
.08	17.0	.12	.....	.034	.032	.033	.033
			Heated to 1550° F.—1 Hour at Heat—Furnace Cooled to 1200° F.—2 Hours at Heat Furnace Cooled to 900° F.—Then Cooled in Air				
.12	12.0	.28	.....	.527	.427	.479	.478
.09	12.3	.33	.46 Mo.	.271	.302	.250	.274
.07	13.4	.28	.27 Al.	.089	.....	.089	.089
.06	12.7	....	.50 Cb.	.025	.246	.282	.184
.08	17.0	.12	.....	.038	.037	.048	.041

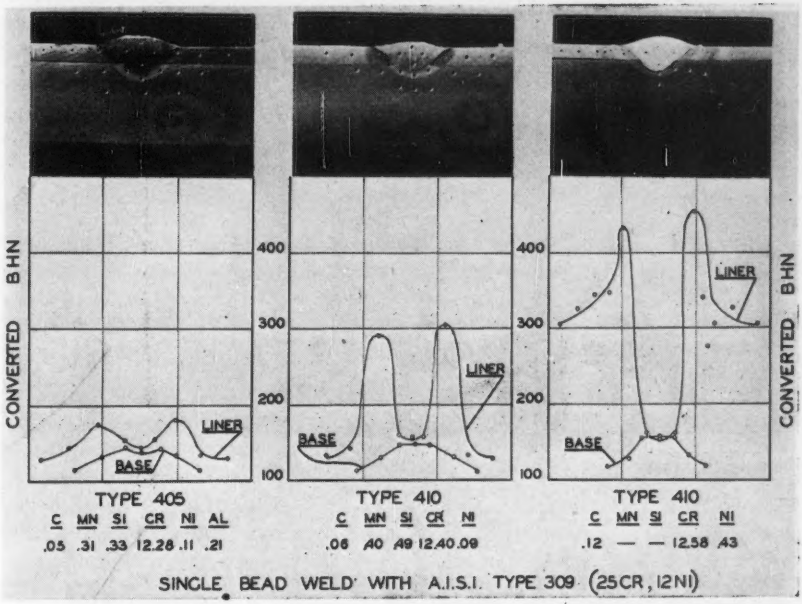


Figure 9—Hardness traverse across single bead butt welds made in Type 405, 410 (0.06% carbon) and 410 (0.12% carbon) compositions.

18% chromium—8% nickel alloys show a definite superiority. The types of cross welded and stress corrosion specimens mentioned are shown in Figures 11 and 12. A 25% chromium — 12% nickel electrode composition is usually used for welding the 12% chromium alloys for lining applications.

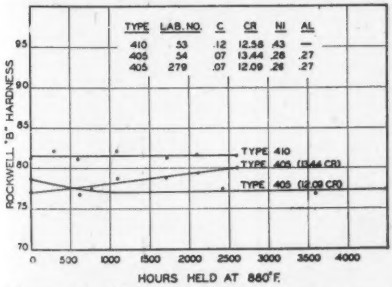


Figure 10—Hardness versus time at temperature for Types 405 (13.44% chromium), 405 (12.09% chromium) and 410 compositions.

So far as determining the suitability of an alloy for an intended service, only a service exposure test of the type just shown is considered to have merit. In the laboratory, corrosion testing is limited to one or two standard tests. These standard tests are helpful in permitting a comparison between alloys or determining the effect of heat treatments on individual alloys. Tabulated in Table III are results of testing several straight chromium alloys with various heat treatments in the 65% boiling nitric acid or Huey test. This test shows a prom-

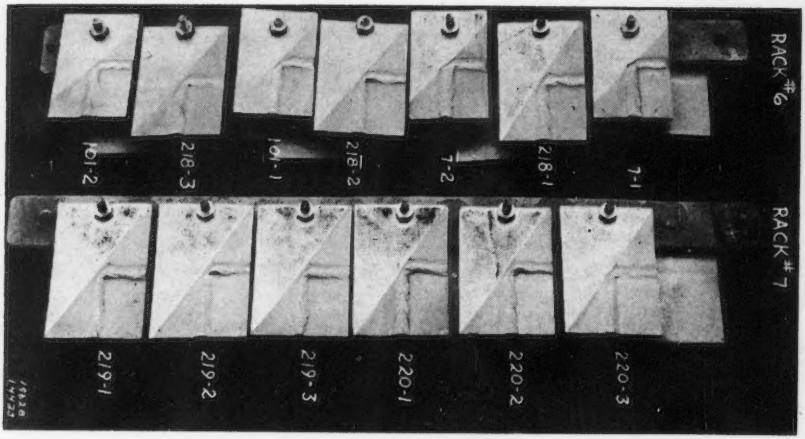


Figure 11—Typical cross welded corrosion specimens mounted on racks for exposure test.

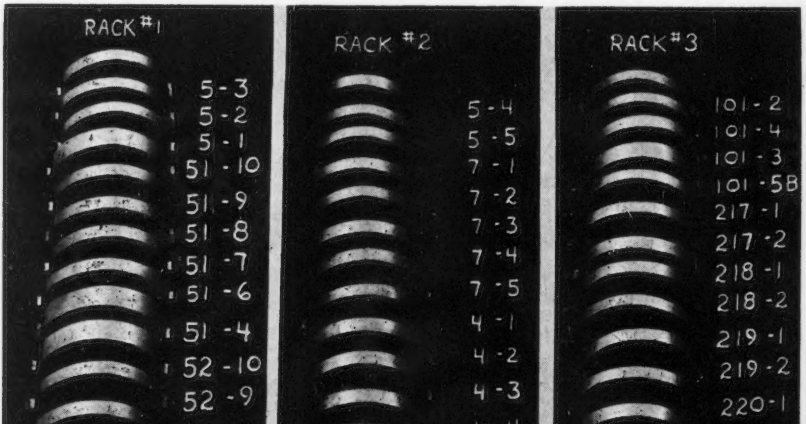


Figure 12—Typical stress corrosion specimens mounted on racks for exposure test.

inent advantage for the 17% chromium analysis which is in line with the popularity of this analysis for nitric acid handling equipment. The addition of molybdenum and columbium on the basis of this test improves the resistance of the 12% chromium analysis. The 13½% chromium composition with the aluminum effects a further improvement.

Summary

The 12% chromium steels have played an important role in providing protection for refinery pressure vessel equipment. The 12% alloy has gradually replaced the higher 17% chromium composition for the reason of the 17% chromium's dangerous embrittling characteristics after exposure in the 750°-950° F. temperature range, a range which includes many modern refining operations. From earlier uses in reaction and coke chamber service, together with fractionator and bubble tower service, to its latest use as a lining for catalytic reactors involving temperatures up to 1000° F., the 12% chromium composition has performed satisfactorily. An addition of 0.25% aluminum to the 12% chromium analysis further enhances its suitability for a lining material, the aluminum restricting the objectionable air-hardening characteristics of the 12% chromium analysis. Plant exposure and laboratory corrosion programs carried out on the aluminum bearing composition have revealed no harmful effect from the aluminum addition on corrosion qualities or susceptibility to embrittlement.

Acknowledgment

The author wishes to thank the A. O. Smith Corporation for permission to publish the data included herein, Mr. M. A. Scheil, Director of Metallurgical Research, for his counsel on the subject and Messrs. W. O. Parrish and T. Gaulke for their assistance with the graphic illustrations.

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Progress Report on the Behavior of Zinc-Iron Couples in Soils

By Melvin Romanoff

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IN ORDER to study the effectiveness of zinc for the cathodic protection of iron and steel under various soil conditions, zinc-iron couples were buried at eight test sites by the National Bureau of Standards in 1941. The galvanic currents produced by the couples and the potentials of the separate elements were measured when the couples were installed and as often thereafter as opportunity permitted. The couples have been removed from two of the sites, and it is planned to remove the remaining couples in the near future. Although the degree of protection afforded by coupling zinc to iron is definitely known at only two of the sites, it has been considered worthwhile to report at this time the behavior of the couples as indicated by the electrical measurements.

Methods

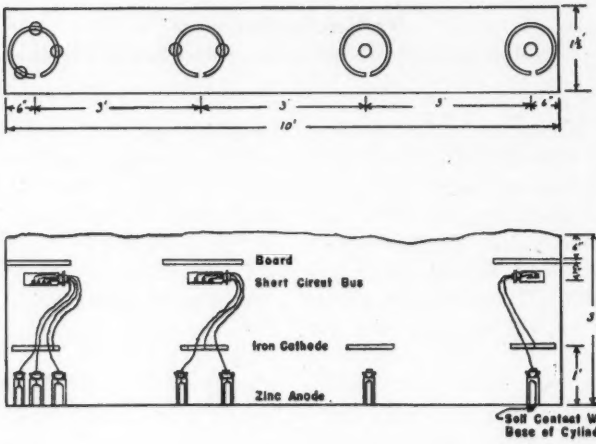
The design of the couples and their installation at the test sites were based on preliminary laboratory studies (1). Under laboratory conditions it was found that the maximum variation in the current density over the surface of the steel cathode was 12 percent.

Each couple consisted of an iron cathode in the form of a ring connected to one, two or three cylindrical zinc anodes, to give ratios of the area of iron to zinc of 20, 10, and 6, respectively. The entire surface of the rings was in contact with the soil. The zinc cylinders, which were completely coated with a bituminous material except at the base, were surrounded by bottomless glass jars so that only the bases of the cylinders made contact with the soil. The zinc cylinder was free to move vertically within the jar, so that firm contact with the soil could be maintained as the base corroded. The area of each iron ring was 48 square inches and the area of the base of each zinc cylinder was 2.4 square inches. In addition, one unconnected iron ring and one zinc cylinder were buried at each test site. The arrangement of the couples at each site is shown in Figure 1.

The electrical measurements which were made at the time of installation, and at one or more inspection periods were of: 1, the current flowing in the galvanic circuit; 2, the potential of each electrode with respect to a copper-copper sulphate electrode after opening all circuits for one-half hour; 3, the voltage of the couple; and, 4, the current required for cathodic protec-

FIGURE 1

ARRANGEMENT OF ZINC–IRON COUPLES



tion of the iron rings. This latter measurement was made at two sites only.

The measurements of electrode potentials and current were made by means of an instrument which is a combination of a potentiometer-voltmeter and a zero-resistance milliammeter, or by means of improvised instruments utilizing the same circuits. The total current produced by each group of anodes was first measured, after which the current produced by each anode was measured while the other anodes remained in the circuit. By this latter procedure the failure of any anode to produce its proportionate share of current could be noted.

Two methods for measuring the current required to protect the iron cathodes were used. In making the first set of measurements at sites 71 and 72 after exposure of the couples for 0.73 year, the potential, including the IR drop, was first measured for a given current. The current was then increased by a small increment, say 10 percent, and the corresponding change in potential noted. The product of the fraction and the applied current gave the IR drop. Subtraction of this value from the potential including the IR drop gave the true potential. The second set of measurements, made after three years' exposure at site 72, was obtained by a null method, which provides for the automatic elimination of the IR drop. The circuits employed by both methods have been previously described (2).

Copper - copper sulfate electrodes were used as reference electrodes in both methods.

The minimum protective current was obtained from a current-potential curve. If the potential of the cathode is plotted against the logarithm of the impressed current, the resulting curve will consist of a horizontal and a sloping line connected by a curved section. The intersection of projections of the straight lines indicates the current required to prevent corrosion (Figure 2). Under certain soil conditions a third sloping line intersecting the second is observed at the highest currents. The significance of the various sections of the current-potential curves has been discussed by Gatty and Spooner (3).

Electrical Measurements

1. Electrode potentials and galvanic currents.

The measurements of electrode potentials and currents made on the couples at the eight test sites are tabulated in Table 1. The currents are expressed as cathode current density since this is the unit commonly used by pipe-line engineers in expressing measurements made in connection with cathodic protection. Omitting the initial measurements because the electrodes may not have become completely stabilized, the potential of steel is seen to vary from 0.413 to 0.96 volt, a range of 0.547 volt. Zinc, on the other hand, varied in potential only between 1.025 and 1.140 volts, a

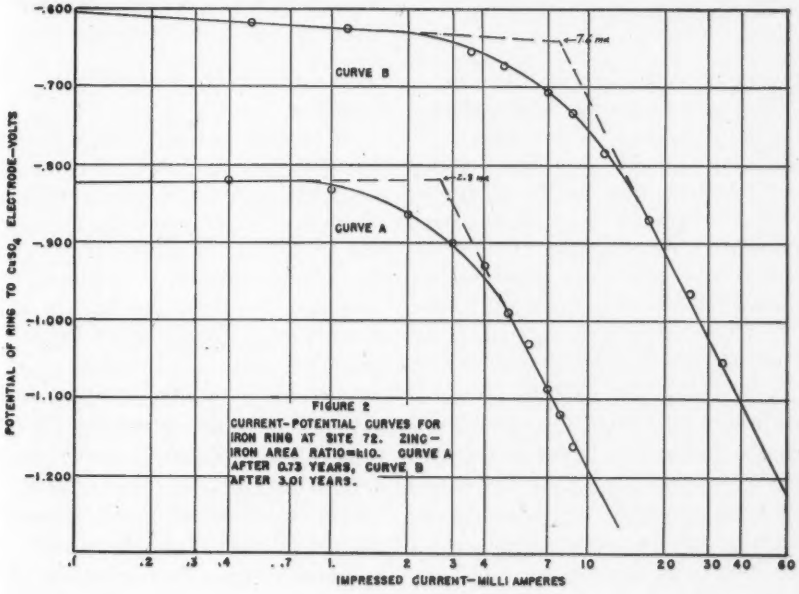


FIGURE 2
CURRENT-POTENTIAL CURVES FOR IRON RING AT SITE 72. ZINC-IRON AREA RATIO=110. CURVE A AFTER 0.73 YEARS, CURVE B AFTER 3.01 YEARS.

Figure 2.

TABLE 1

Summary of Potential and Current Measurements of Zinc-Iron Couples

Site No.	Soil Type	Location	pH	Resistivity @ 60° F. Ohm-cm	Duration of Exposure Years	Average Potential*		Average Voltage of Couples Volts	Cathode Current Density		
						Iron Cathodes Volts	Zinc Anodes Volts		1 Anodes ma/ft²	2 Anodes ma/ft²	3 Anodes ma/ft²
71	Mahoning Silt Loam	Austintown Junction, Ohio	7.1	2582	0.0	0.590	1.098	0.497	1.29	1.40	1.90
					0.32	0.591	1.125	0.539	2.71	3.87	3.79
					0.72	.....	.....	.....	1.80	3.34	4.31
					3.02	0.543	.....	0.584	1.24	3.26	5.82
72	Papakating Silty Clay Loam	Deerfield, Ohio	7.2	762	0.0	0.727	1.140	0.389	2.12	4.24	7.71
					0.31	0.792	1.052	0.263	0.71	1.20	3.32
					0.73	0.778	1.051	0.272	1.03	1.92	3.39
					1.04	0.744	1.052	0.300	1.57	2.83	3.89
					3.01	0.684	.....	0.339	1.51	2.45	0.24
73	River Silt	St. Louis, Missouri	6.8	521	0.0	.....	.....	.....	6.69	13.39	13.39
					0.68	0.913	1.122	0.223	1.62	2.88	2.81
74	Otero Clay Loam	Rocky Ford, Colorado	7.3	436	0.0	0.740	1.180	0.415	20.94	.....	.....
					0.54	.....	.....	.....	0.81	1.28	1.31
					2.23	.....	.....	.....	1.69	3.20	1.43
75	Alkali Soil	Albuquerque, New Mexico	8.4	379	0.0	0.716	1.163	0.431	17.16	34.03	44.22
					0.53	0.810	1.08	0.270	13.67	15.71	15.71
76	Chino Silt Loam	Los Angeles, California	9.2	2650	0.0	0.503	0.952	0.436	0.46	1.53	4.10
					0.26	0.675	1.061	0.391	4.13	6.69	9.52
					0.47	0.610	1.034	0.439	4.04	13.07	9.98
					0.80	0.524	1.038	0.512	8.88	5.76	17.90
					1.28	0.413	1.025	0.634	6.55	4.92	11.90
					1.49	0.758	1.033	0.277	4.51	4.13	1.80
77	Susquehanna Clay	Louisville, Mississippi	4.3	9390	0.0	0.565	.....	0.404	1.51	1.76	2.06
					0.54	.....	.....	.....	0.29	1.54	2.71
78	Caddo Fine Sandy Loam	Shreveport, Louisiana	4.5	821	0.0	0.717	1.12	0.412	11.06	15.56	19.78
					0.27	0.96	1.05	0.09	2.01	5.82	4.68
					0.48	0.93	1.11	0.162	2.33	5.21	4.10
					0.84	0.80	1.08	0.267	6.98	14.26	10.71
					1.17	0.777	1.077	0.288	4.36	5.50	3.64
					3.14	.....	.....	.....	5.82	4.71	5.67

* With respect to a copper-copper sulfate electrode.

maximum difference of 0.015 volt.

The wide range in potential shown by the iron rings is due largely to differences in the aeration of the soil. Where the soil is saturated over the greater part of the test period, as for example at sites 72 and 78, the numerical values of potential are relatively high, but where the soil is fairly well aerated, e. g., sites 71 and 76, the potentials are low. Taking the data for site 76, Gilbert and Corfield (4) observed a rough correlation between the potential and the season. It was noted that, in general, the open-circuit voltages of the couples were greatest during the dry season, and lowest during the wet season, when of course the aeration of the soil was least.

At certain test sites, for example No. 72, the galvanic current is roughly proportional to the number of anodes. At certain other sites, on the other hand, notably sites 73 and 78, no more current is produced by two than by three anodes. In the absence of polarization on the iron ring, increasing the number of anodes would naturally be expected to produce a rough proportional increase in the galvanic current. However, when cathodic polarization becomes an important factor, increasing the number of anodes would be expected to have little effect on the current flow since the original volt-

age of the couple would be opposed by a counter electromotive force.

The effects which have been cited can be interpreted in terms of the degree of protection likely to be afforded the iron cathodes by consideration of current-potential curves, such as those shown in Figure 2. So long as increasing the number of anodes does not cause the potential to depart from the horizontal part of the curve, an increase in current results, but corrosion will not be prevented. Hence, one would infer that the rings at site 72 are not being protected cathodically. On the other hand, if increasing the number of anodes should cause the potential of the cathode to lie along the sloping part of the curve, no appreciable increase in current would result. Then the ring would be protected cathodically because the minimum protective value, as indicated by the current density at the intersection of the straight portions of the curves, would have been exceeded. One would predict, therefore, that the rings at site 78 would be protected by two anodes and probably by only one.

TABLE 2
Protective and Galvanic Currents of Zinc-Iron Couples

Site No.	Duration of Exposure Years	Area Iron to Zinc Ratio	Protective Current Density On Iron Ma/Sq. Ft.	Galvanic Current Density On Iron Ma/Sq. Ft.
71	0.72	20	6.3	1.80
		10	4.8	3.35
		6.7	....	4.31
72	0.73	20	18.6	1.03
		10	8.4	1.92
		6.7	8.4	3.39
72	3.01	20	49.5	1.51
		10	22.8	2.45
		6.7	....	0.25

TABLE 3
Loss of Weight and Depths of Maximum Penetration of Couples Buried at Los Angeles, California†

Specimen*	LOSS OF WEIGHT		Maximum Penetration Mils
	Grams	Oz/Sq. Ft.	
Steel No. 21.....	45.895	4.86	70
Zinc No. 36.....	0.375	....	..
Cathode No. 22....	27.298	2.89	78
Anode No. 37.....	33.785	....	..
Cathode No. 23....	17.088	1.81	35
Anode No. 38.....	16.192	....	..
Anode No. 39.....	22.898	....	..
Cathode No. 24....	15.275	1.62	41
Anode No. 40.....	31.628	....	..
Anode No. 41.....	14.922	....	..
Anode No. 42.....	26.288	....	..

† Duration of exposure = 1.49 years.
* Numbers 21 and 36 unconnected.
Numbers 22 and 37 connected.
Iron-zinc ratio = 20.
‖ Numbers 23, 38 and 39 connected.
Iron-zinc ratio = 10.
Numbers 24, 40, 41 and 42 connected.
Iron-zinc ratio = 6.7.

In general, little or no diminution of current has occurred at the test sites with the exception of site 76. It is possible that the reduction in the current at this site has been caused by the accumulation at the base of the connected anodes of a white deposit of zinc carbonate which, according to Gilbert and Corfield, varied in thickness from 0.069 to 0.20 inch.

2. Protective currents.

At sites 71 and 72 the currents required to protect the iron rings were measured. The data in Table 2 show that the galvanic currents for every couple for which the protective current was measured are less than the protective current, which indicates that none of these couples was completely protected. Although the protective current for the couple containing three anodes at site 71 was not measured, the trend of the data

indicates that the protective current may be taken as approximately equal to the galvanic current.

Figure 2 shows current-potential curves for the two-anode installation at site 72 for two inspection periods. It should be noted that the minimum protective current has increased with time, which indicates an increase in the rate of corrosion. The lower potential of the cathode shown in curve B (Figure 2) indicates improved aeration of this normally poorly drained soil.

Measurements of Loss in Weight and Pitting

The final criteria for determining the extent of protection offered to the iron by the zinc are the loss of weight and the extent of pitting. The couples have been removed from sites 76 and 78. Gilbert and Corfield described the behavior of the zinc-iron couples buried 1.49 years at site 76. Table 3 shows the results of the measurements. Although the losses of weight of all the protected rings were less than the loss of the unprotected ring, and the maximum pit depths of the rings connected to the two and three anodes were less than the maximum pit depth for the unprotected ring, adequate protection was not afforded.

The couples having area ratios of 20 and 6.7 were removed from site 78 after exposure for 3.14 years. Table 4 shows the losses of weight and depths of maximum penetration for the iron rings. It is apparent that the zinc has been effective in offering almost complete protection

TABLE 4

Loss of Weight and Depths of Maximum Penetration of Couples Buried at Shreveport, Louisiana†

Specimen*	LOSS OF WEIGHT		Maximum Penetration Mils
	Grams	Oz/Sq. Ft.	
Steel No. 29.....	67.328	7.12	84
Zinc No. 50.....	0.815	....	..
Cathode No. 30....	1.768	0.19	7
Anode No. 31.....	43.070	....	..
Cathode No. 31....	1.360	0.14	4
Anode No. 54.....	24.870	....	..
Anode No. 55.....	19.007	....	..
Anode No. 56.....	19.700	....	..

† Duration of exposure = 3.14 years.
* Numbers 29 and 50 unconnected.
Numbers 30 and 31 connected. Zinc-iron ratio = 1:20.
Numbers 31, 54, 55 and 56 connected. Zinc-iron ratio = 1:.6.

to the rings at this site. A film of white corrosion products was found on the base of each zinc anode. The data in Table 4 indicate that one anode offered as much protection to the iron ring as three anodes. The protection measured by the loss of weight and depths of pitting is in accord with the measurements of galvanic current at this site. It will be recalled that from these measurements it was predicted that the rings could be protected by two anodes and probably by only one.

Since the corrosion on the unconnected ring at site 76 is less than on the corresponding ring at site 78, and the losses of weight of the connected zinc anodes and the magnitude of the galvanic currents at site 76 were at least as great, if not greater than at site 78, it is surprising that adequate protection was not obtained at the latter site. The difference in effectiveness of the galvanic current can be explained on the basis of differences in distribution of the currents between

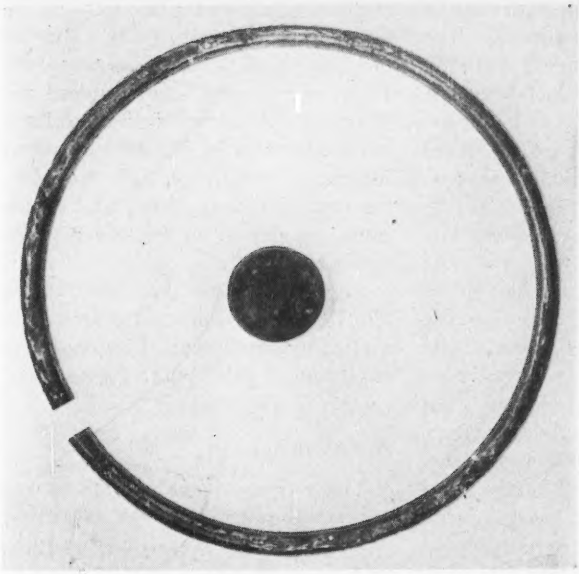


Figure 3 — Condition of unprotected iron ring and zinc buried 3.14 years in Caddo fine sandy loam at Shreveport, Louisiana.

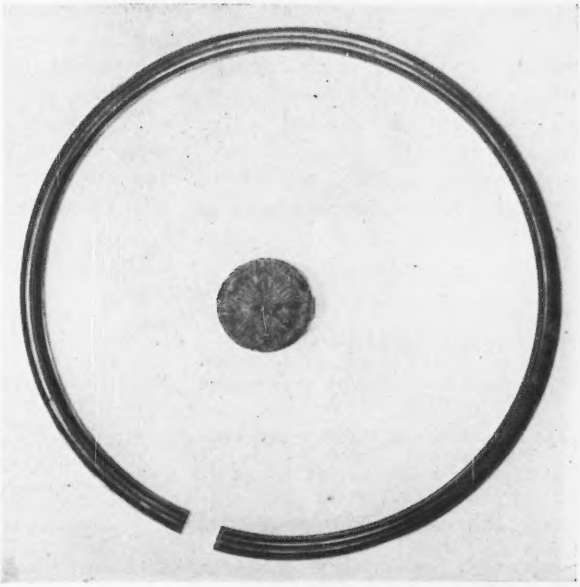


Figure 4 — Condition of iron ring cathodically protected by one zinc anode (center) buried 3.14 years in Caddo fine sandy loam at Shreveport, Louisiana.

the anodic and cathodic areas of the local action circuits on the iron rings. The partitioning of cathodically applied current has been explained by Pearson (5) as being determined by the relative resistances of the anodic and cathodic areas on the corroding metal. If the resistance of the anodic areas is very low relative to that of the cathodic areas, the greater part of the applied current is utilized in opposing the local action current proceeding from the anodic areas. This is the condition for maximum efficiency of protection by the applied current. However, if the reverse were true, that is, if the resistance of the local anodes were relatively great, a large part of the applied current would be shunted through the cathodes. Since a relatively small part of the applied current would be available for opposing the local action current, the efficiency of the applied current would be very low.

The amount of corrosion on the rings connected to the zinc anodes at site 78 was reduced to such an extent that it is negligible compared to the corrosion on plain steel in the least corrosive soils in the Bureau of Standards soil-corrosion tests. Plain open-hearth steel exposed approximately 4 years to the two least corrosive soils in the tests showed losses of weight of 2.58 and 4.21 ounces per square foot, and maximum pit depths of 54 and 22 mils respectively (6).

Figure 3 shows the condition at site 78 of the unconnected iron ring and zinc anode and Figure 4 the condition of the iron ring connected to the single anode.

Acknowledgment

The writer wishes to express his appreciation to the many corrosion engineers who are cooperating in this investigation, particularly to Mr. R. F. Hadley of the Susquehanna Pipe Line Company for making the protective-current measurements, and to Mr. K. H. Logan for installing the tests. The assistance of Dr. I. A. Denison, who made many helpful suggestions regarding the interpretation of the data, is also acknowledged.

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6. Soil-Corrosion Studies, 1941: Ferrous and Non-Ferrous Corrosion-Resistant Materials and Non-Bituminous Coatings. K. H. Logan and Melvin Romanoff, J. of Research NBS, **33,** 145, (1944) Sept.

Corrosion Abstracts

BEARING CORROSION

Bearing Corrosion Characteristics of Lubricating Oils. Indiana Stirring Corrosion Test. C. M. LOANE and J. W. GAYNOR. Standard Oil Company (Indiana), Whiting, Ind. Ind. Eng. Chem. Anal. Ed. **17**, 89 (1945) Feb.

Comparison of a modification of the Indiana stirring test with Chevrolet 36-hour test is reported. Seven oils were chosen for investigation of the effect of different catalysts. Corrosion of lead strip was chosen as index of corrositivity as experience of authors indicate it to be more significant with respect to copper-lead bearings in engine service than is the corrosion of copper-lead, copper or cadmium-silver strips. Lead strip corrosion is due either to oil oxidation or to the specific effect of additives. It is generally believed that copper-lead bearing corrosion in the engine is due to selective removal of lead. The effect of crankcase catalysts (crankcase drainings containing 45% lead and 2% iron), inorganic iron catalysts (1) reduced iron powder and (2) ferric chloride and inorganic lead catalysts. The crankcase catalysts correlated very poorly with the Chevrolet test. Neither iron powder nor iron chloride showed any correlation. Definite correlation was found between inorganic lead catalysts and the Chevrolet tests. Tests showed that lead from fuel can act either as an inhibitor or as an accelerator of corrosion. Although this particular correlation was good, the Indiana stirring corrosion test, like all beaker tests, does not exactly duplicate all conditions found in engine tests, i. e. (1) the continuous addition of lead catalysts and partially oxidized hydrocarbons from fuel blow-by (2) local hot spots which may either accelerate or retard corrosion rate.

Laboratory Machine for Investigating Corrosion of Bearings. S. K. TALLEY, R. G. LARSEN and W. A. WEBB. Shell Development Company, Emeryville, Calif. Ind. and Eng. Chem. Anal. Ed. **17**, 168 (1945) Mar.

The thrust bearing corrosion machine has been designed to simulate the important mechanical conditions of engine bearing corrosion. It incorporates standard steel-backed bearing speciments, ease of thorough cleaning, minimum demands on the operator's time, adaptability to multiple set-up, reasonable cost, good control or experimental conditions and a small sample. Bearing surfaces are mirror finished. In testing bearing metals the babbitts showed a relatively high resistance to corrosion while the harder bearing metals, copper-lead, copper-nickel and cadmium silver are all subject to corrosion. Presence of asphaltense caused excessive heating of bearings which could be inhibited by addition detergents. Ref-

erence is made to metallographic examinations of copper-lead bearings which shows that lead is sometimes leached out leaving original surface containing only copper. An oil showing a thrust bearing corrosion test (20 hrs.) of 1 mg. per sq. cm. is potentially corrosive, of 5 mg. per sq. cm. is definitely corrosive and of 0.3 mg. per sq. cm. or less is considered negligible. Temperature is very important factor.

Measuring the "Existent Corrosivity" of Used Engine Oils. R. G. LARSEN, F. A. ARMFIELD and L. D. GRENOT, Shell Development Co., Emeryville, Calif. Ind. and Eng. Chem. Anal. Ed. **17**, 19 (1945) Jan.

A test for determining the "existent corrosivity" of used engine oils independently of previous history provides a means of evaluating in simple fashion, by the use of test strips coated with lead or other metal in graduated thicknesses, a property of used oils not heretofore satisfactorily measured by routine engine oil tests. It also has practical application in determining the cause of bearing failures and indicating necessary oil drain periods. Bearing failures may be traceable to mechanical factors such as poor alignment and fit, poor cooling due to insufficient oil flow, poor bonding of the bearing alloy to the backing, or imperfect structure of the alloy, or to weakened structure as a result of chemical attack. In developing corrosion test strips it was found that only lead is attacked in copper lead bearings so lead was plated on copper to produce coatings of desired thicknesses. Oil may be tested by this method directly in the engine or in removed oil. Outstanding feature of test is that it provides a simple method for following the development of corrosiveness in engine oil during use and may be used as an aid in determining appropriate drain periods for oil in service. Application to used oil is superior to acidity test for determining role of oil in a particular bearing failure.

Corrosion of Metals by Organic Acids in Hydrocarbon Solvents. C. F. PRUTTON, D. R. FREY, D. TURNBULL and G. DLOUHY. Case School of Applied Science. Ind. Eng Chem. **37**, 90-100 (1945) Jan.

Investigation was made to evaluate the most important factors involved in bearing corrosion and to study the mechanism of the reaction. Factors considered were oxygen pressure, nature of metal and solvent, nature and concentration of acid and of peroxide, temperature and time. Lead and cadmium were chosen as test metals. Presence of molecular oxygen and peroxides found necessary to produce any appreciable corrosion. Presence of acid necessary but corrosion rate is not dependent on amount of acid. At temperatures around 100° C. or lower, molecular oxygen is an important factor in bearing corrosion while at higher temperatures peroxide formation is the principal factor. This investigation confirms the major portion of Denison's work published

in Ind. Eng. Chem. 36, 477 (1944). Effect of dissolved oxygen at lower temperatures however was not reported by Denison.

Testing the Running Properties of Bearing Metals. E. v. RAJAKOVICS. Metallwirtschaft 22, 361-8 (1943). Chem. Zentr. 1943, II, 2313.

Description of a new bearing tester shows that bearing excess temperature and friction number are inversely proportional to the bearing play and the lubricating-oil fluidity. The new Al. bearing metal "Rotinal" containing about 2% Fe and Si has shown itself as good as the Pb bronze. C. A. **39**, 682 (1945) Feb. 20.

The Possibilities of Substitution for Tin-base Bearing Materials. JOHN H. KITTLE. Wash. State Coll., Electromet. Research Lab. Inf. Circ. **50**, 1-15 (1943).

Review with 18 references. C. A. **39**, 682 (1945) Feb. 20.

METAL FAILURES

Stress-Corrosion Cracking of Metals; Summary of Symposium. Min. & Met. **26**, 40 (1945) Jan.

Twenty-nine papers were presented to 350 people at the Stress Corrosion Cracking Symposium in Philadelphia, Nov. 29-Dec. 1. 13 papers covered latest data on methods of testing for (1) susceptibility to and (2) protection from, stress corrosion cracking, (3) detection of cracks, (4) measurement of residual stress, (5) latest theories on the mechanism of stress corrosion cracking of copper-base alloys. Outstanding feature of the stress corrosion cracking susceptibility test methods was the trend toward the use of an ammonia test instead of the universal mercury test. Procedures for protecting material from stress corrosion cracking presented were: stress relief annealing; protective resin films; and control of processing variables to reduce residual stress. Two methods of detecting stress corrosion cracks were given: one based on higher damping capacity which accompanies season-cracked material; the other based on effect of cracks on the eddy currents reduced in a material by a changing magnetic field. Seasoned cracking of brasses was discussed and proposed mechanism was one of electropotential difference between grains and grain boundaries.

Seven papers were given on stress corrosion cracking of aluminum and magnesium base alloys which included tests for susceptibility to stress corrosion cracking, theory of mechanism and case histories. Salt solutions used for testing susceptibility. A new method reported on aluminum alloys used potential measurements of grain and grain boundary to predict susceptibility. The theory proposed as a mechanism of stress corrosion cracking of all alloys included the following: 1, tensile stresses are required; 2, corrosion occurs along localized paths; 3, these paths are areas of lower resistance to corrosion; 4, corrosion occurs by electrochemical mechanism, the localized paths being the anodic area; 5, anodic and cathodic areas

change with corroding environment; 6, stress opens the corroded localized paths.

Four papers were presented on stress corrosion cracking of stainless steels.

Failure of Spring Loops by Stress Corrosion Cracking. GIVEN BREWER, Stress Analyst, and HERMAN C. IBSEN, Metallurgist, Consolidated Vultee Aircraft Corp. Metal Progress, **47**, 707 (1945) Apr.

A shipment of several thousand spring clips was found to be defective. The looped end of the wire could be twisted off with very little force and microscopic examination of the looped ends revealed the presence of radial cracks. Investigation showed that the springs had been cold formed and heated to 500°F. for stress relief and processed by immersing in caustic electrolytic cleaner for 5 to 10 minutes, then immersed in 10% HCl for 5 to 10 minutes, washed and dried. Further experiments indicated that heating of springs thus treated to 1450°F would relieve the stress. Further tests indicated high carbon cold-drawn wire is far more resistant to stress corrosion cracking than is heat-treated wire of the same strength and chemical content.

Intergranular Corrosion of Stainless Steel Welds. W. T. TIFFIN, Research Engineer, Eng. Exp. Stat., Univ. of Fla. Welding J. **24** Sup. 125, (1945) Feb.

Observers are fairly in agreement that the characteristic formation is due to the precipitation of a chromium-rich carbide from solution and that the carbide precipitates from solution upon slow cooling through some temperature range that is characteristic not only of the composition of the alloy but also of the treatment to which the alloy was subjected before placing in service. X-ray analysis discloses the presence of complex chromium carbides and indicates chemical composition of Cr_4C to Cr_3C with Cr_7C_3 being an intermediate composition. Susceptibility to chromium carbide precipitation may be decreased by lowering the carbon content or stabilizing the alloy with columbium, titanium or molybdenum. Microscopical examination of welds shows chromium carbide precipitation may be homogenized by proper heat treatment. The heat treatment should involve a quench from a suitable temperature which should be followed by a normalizing or spheroidizing treatment.

Intercrystalline Corrosion Cracking on Preheater Tube. W. MANTEL. Z. Ver. deut. Ing. **88**, 238-40 (1944).

A type of intercrystalline crack in feed water tubes made of 0.1% C steel is described which resembles stress-corrosion cracking but differs from it in the net-like pattern and the fact that the cracks can be partly cured by annealing. It is concluded that the cracks originate in a network of fissures in the oxide scale adhering to the tubes. Mechanical expansion causes splitting of the oxide filling within these

cracks permitting continuation of the attack into the interior of the tube wall but following the general pattern of the original cracks in the scale. On annealing at 1300° F., the crack can be partly eliminated by reduction of the oxide which is accompanied by decarburization of the adjoining metal. C. A. **39**, 1385 (1945) Apr. 10.

BRITISH NON-FERROUS METALS RESEARCH ASSOCIATION

Survey of Work Done by B. N. F. R. A. Private Communication from E. A. G. Liddiard, Research Manager, to F. N. Speller.

B. N. F. M. R. A. is one of the industrial research associations sponsored by the Department of Scientific and Industrial Research in which appropriate sections of the industry subscribe to finance on a cooperative basis basic research on problems which are of common interest The association was organized in 1920. Work was started on the atmospheric corrosion of nonferrous metals with W. H. F. Vernon and J. C. Hudson as official investigators. Twelve papers on this subject were published from 1924 to 1932. Other research and publications have included work on condenser tubes which led to the development of aluminum brass, oxidation of copper, atmospheric corrosion of tin, studies on zinc coatings, corrosion of lead by water, and bacterial corrosion. Recent work has included studies on aluminum welds, behavior of copper-nickel alloy condenser tubing, corrosion of copper water pipes, zinc and galvanized coatings, and corrosion of lead. Work which has not been reported and which has been held up by the war includes "The Intercrystalline Failure of Brasses Containing the Beta Constituent" and "The Stress Corrosion of Aluminum Alloys Containing Magnesium." Some preliminary work has been done on soil corrosion and on the effect of chlorination on the corrosion of various non-ferrous metals by domestic water.

WATER CORROSION

Control of Compressor Cooling Water. E. G. HAMMERSCHMIDT, Chief Chemist, Texanna Natural Gas Company. Petr. Eng. **16**, 192 (1945) Mar.

Ryznar stability index used as a criterion of quality of cooling water. As the Ryznar stability index falls below 6.3, the water becomes increasingly scale-forming; between 6.3 and 7.0, the water is practically in chemical balance; above 7.0 the water dissolves scale and corrosion might result. Formula given for estimating temperature range of chemical stability of a water. Waters under consideration were all softened, some by lime and others by zeolite. Hydrogen zeolite provided considerable saving at one plant by reducing blowdown from 40 to 10%. Chlorine and chlorine plus ammonia used for slime control. Found both chlorine and chloramine to cause some increase in corrosion rate.

Correcting Problems Caused by Scale and Corrosion in Compressor Stations. PAUL V. SANDERS, Chem. Engr., D. W. Haering & Co., Inc., Petr. Eng. **16**, 208 (1945) Mar.

Very hard waters require both external and internal treatment. Concentrations of solids must be kept at a reasonable figure. Beta-glucoside and certain of its derivatives may be used for the prevention of scale formation in compressor station cooling water systems. Corrosion is associated with oxygen, carbon dioxide, sulfide and chloride content of water. Film inhibitors used to avoid corrosion. Use of glucosides and chrom glucosates discussed as well as importance of design to prevent voltaic cells and eliminate undue turbulence.

Corrosion by Water Explained from the Operator's Viewpoint. A. C. JANZIG. Water Works Engineering, **98**, 136-137, 158-160 (1945), Feb. 7.

Discusses some chemical relationships in the action of corrosion by natural, oxygen-containing waters, especially on the interior of iron and steel pipe.

Special Problems Connected With Pumping Water Containing Acid. J. W. PIRIE. Iron and Coal Trades Review, **150**, 275-277 (1945), Feb. 23.

Discusses experience in pumping acid mine water. Deals with effect of this water on pumps, pipes, and valves made of phosphor bronze and various ferrous compositions under conditions where velocity of water was moderate and where water had high velocity at high pressure.

CONCENTRATION CELLS

Practical Precautions for Preventing Concentration Cell Corrosion. Steel, **115**, 136 (1944) Nov. 13.

1. In new equipment specify butt welded joints.

2. Avoid lap joints or seal completely.

3. Lap or spot-welded joints should be cleaned and repaired as soon as evidence of crevice corrosion is apparent.

4. In vessel design avoid sharp corners and stagnant areas where solids might accumulate.

5. Clean areas subject to accumulations frequently.

6. In design and operation of tubular flow heat exchangers, endeavor to provide for uniform flow of liquid with a minimum of turbulence and impingement.

7. Provide suitable strainers in heat exchanger cooling medium lines and prevent local obstruction.

8. Remove all wet packing materials during long shutdown.

9. Prevent wooden tank leaks as protection to tie rods.

HANDLING CORROSIVE GASES

Dispersal of Corrosive Gases. Chem. Ind. **55**, 954 (1944), Dec.

Technique employed in new laboratories building of the St. Lawrence Alloys and Metals, Ltd. at Beauhamois, Quebec. Two 8″ i. d. flues of corrosion resistant carbon pipes were built into the chimney to carry the gases and protect the brickwork. Two flues were constructed to keep separate those

gases that might produce an explosion if mixed. No. 1 carbon tube carries hood gases containing ammonia, hydrochloric acid, ether and ethyl acetate. No. 2 carries hydrofluoric acid, sulfuric nitric, perchloric acid gases and chlorine. Condensation is provided for by having carbon drip pipe spillways.

CAN FAILURES

Diagnostic Methods in Problems Concerned With the Corrosion of Cans. W. B. ADAM and D. DICKINSON. Chemistry and Industry, 1944, 426-8. C. A. **39**, 896 (1945) Mar. 10.

The following tests are discussed: 1, internal and external inspection of the cans; 2, thickness of the tin coatings; 3, corrodibility of the steel base; 4, analysis of the steel base; 5, determination of the original vacuum; 6, gas analysis; 7, determination of pH and acidity; 8, determination of tin and iron contents; and, 9, corrosivity of canned material.

PIPELINE CORROSION

Relation of Wall Thickness to Pipe Life. K. H. LOGAN, Research Associate, Cast Iron Pipe Research Association and Chief of the Underground Corrosion Section, National Bureau of Standards. Petr. Engr. **16**, 186 (1945) Mar.

Some interesting comparisons are drawn as to the economics of using cast iron or heavy steel pipe in prolonging the service life of pipe lines in various types of soil, and as mentioned by the author, the conclusions drawn are speculations predicated on functions of local conditions. As applied to present-day pipe line engineering practices, the data presented should be examined in the light of improvements in pipe coatings and application technique and the application of cathodic protection.

GAS AND CONDENSATE WELL CORROSION

Internal Corrosion of Tubing in Gas-Condensate Wells Measured by Recording Calipers. E. H. SHORT, JR., Oil and Gas J. **43**, No. 35, 46 (1945) Jan. 6.

This article describes an instrument which can be run inside the tubing strings, under closed-in pressure to determine the magnitude of corrosion pits. The tool has been successfully used to survey 12 Cotton Valley Operators Committee wells, and while the caliper is still in the development stage, it has possibilities for valuable service.

DIESEL ENGINE CORROSION

Extensive Corrosion in Diesel Starting Cylinders. GREGOR KAISER. Tech. Ubermach **4**, 27-8 (1943); Chem. Zentr. 1943, II, 1316-17.

Description of the corrosion damage to starting cylinders of the Diesel standard gauge locomotives. H_2SO_4 is produced from the exhaust gases of Diesel engines and the H_2O condensed. The service personnel had omitted a regular dehydration of the cylinders. The tanks should be cleaned inside at regular intervals, as at the end of the dehydration tube appreciable residues are accumulated which cause pitting and hinder the withdrawal of fluid. C. A. **39**, 687 (1945).

ARTICLES OF ORGANIZATION
and
BY-LAWS
of the
NATIONAL ASSOCIATION OF CORROSION ENGINEERS

(Effective June 1, 1945)

Articles of Organization

ARTICLE I
(Articles of Organization)
NAME

The name of this Association shall be:
National Association of Corrosion Engineers

ARTICLE II
(Articles of Organization)
OBJECTS

This organization shall be a non-profit, scientific and research association, and its objects shall be:

(a) To promote scientific research in determining the causes of corrosion and methods of its control with respect to theory and practice.
(b) To provide a means of exchange of knowledge and ideas among those individuals actively engaged in the control of corrosion.
(c) To promote methods of control of corrosion.
(d) To promote standardization of terminology, methods, equipment and design in the development of methods of corrosion control.
(e) To foster cooperation between individual owners of metallic structures in the solution of their joint corrosion control problems.

ARTICLE III
(Articles of Organization)
MEMBERSHIP

Section 1. Membership in this Association shall be of four (4) classes: Active, Junior, Corporate, and Associate.

Section 2. AN ACTIVE MEMBER of this Association shall be an individual who is actively engaged in research concerning corrosion, or who is actively engaged in the development, design, and installation of equipment or methods used for the control of corrosion, or the operation and maintenance of structures subject to corrosion.

Section 3. A JUNIOR MEMBER shall be a student or any otherwise qualified person engaged or interested in the advancement of knowledge relating to corrosion control. At the time of his admission he shall be not less than eighteen years of age. His connection with the Association shall cease when he becomes twenty-five years of age, *unless* he is regularly enrolled as a student in a university or has previously transferred to the grade of Active Member. Junior Members shall receive official publications distributed to members and have all privileges of Active Membership except holding office and voting.

Section 4. A CORPORATE MEMBER shall be any company, corporation, utility, association, board, commission, department (State, County, Municipal, Federal) or other body or organization engaged or interested in Corrosion and Corrosion control. Corporate Members are restricted to those who do not primarily produce and sell equipment or materials for the purpose of control or mitigation of corrosion and shall be entitled to one representative whose name shall appear on the roll of members and who shall have all the rights and privileges of an Active Member. This representative may be changed at the convenience and pleasure of the Corporate Member on written notice to the Secretary.

Section 5. AN ASSOCIATE MEMBER shall be any company, corporation or other body or organization engaged in the production or sale or both of equipment or materials for the purpose of control or mitigation of corrosion. Associate Members shall be entitled to one representative whose name shall appear on the roll of members and who shall have all the rights and privileges of an Active Member. This representative may be changed at any time at the convenience and pleasure of the Associate Member on written notice to the Secretary.

ARTICLE IV
(Articles of Organization)
BOARD OF DIRECTORS

Section 1. The Governing Body of the Association shall be a Board of Directors, hereinafter called the Board.

Section 2. The Board shall consist of:

(A) The President of the Association
(B) The Vice President of the Association
(C) The Treasurer of the Association

(D) One Director to be elected by each Regional Division of the Association
(E) Three Directors to be elected from the Active Membership of the Association
(F) Three Directors to be elected from the Corporate Membership of the Association
(G) Three Directors to be elected from the Associate Membership of the Association
(H) The latest living Past President of the Association
(I) The Chairman of the Policy and Planning Committee (Ex-Officio)
(J) The Chairman of the Publication Committee (Ex-Officio)
(K) The Chairman of the Technical Committee (Ex-Officio)
(L) The Chairman of the Regional Management Committee (Ex-Officio)

Section 3. The Terms of the Directors and Officers shall start at the beginning of the last day of the annual convention held subsequent to the date of their election. If, for any reason, a Director is not elected until after the date of the holding of the annual convention at which he should have commenced his term of office, his term of office shall begin at the date that the advice of his election is received by the Secretary. The Terms of Directors and Officers shall terminate at the beginning of the last day of the annual convention in the year of expiration of their terms of office.

If for any reason the annual convention of the Association is not held between January 1 and July 1, in any year, then the terms of newly elected Directors and Officers shall commence on July 1, of such year; and the terms of office of the Directors and Officers who are to be succeeded shall terminate on that date.

Section 4. The President of the Association, the Vice President of the Association, and Directors elected by the Sections of the Association and from the Active, Associate and Corporate Memberships will not be eligible for reelection for consecutive terms.

Section 5. The Officers of the Association shall be the Officers of the Board.

Section 6. The functions of the Board shall include the following:

(a) Establishing policies for the Association and for the Executive Committee, the Technical Committee, the Regional Management Committee, the Publication Committee, and for the Officers.
(b) Providing for the general administration of the affairs and property of the Association.
(c) Fixing the time and place of the annual and other conventions of the Association as provided in the By-Laws.
(d) Preparing and enforcing, for the conduct of the business of the Association, By-Laws not in conflict with these Articles of Organization, and amending the same.

Section 7. The Board may exercise the above described functions either in session at stated or duly called meetings or by letter ballot. Any matter that requires action by the Board of Directors at a time not conveniently related to a regular or called meeting may be submitted to it for approval by letter ballot.

The Board may, by resolution, designate the classes or types of Association business which may be submitted to it for approval by letter ballot. Matters not thus designated may be considered by the Executive Committee in the exercise of its stated duties (By-Laws, Article IV) or the Executive Committee may refer such matters to the Board for approval by letter ballot. Such action by the Executive Committee may be taken either at a meeting of the Committee or by a letter ballot of the Committee if the initiation of said letter ballot is directed by the President in a letter addressed to the Secretary.

Except as otherwise provided by resolution of the Board, matters submitted to it by letter ballot shall obtain an affirmative recorded vote of two-thirds of the Board membership to secure approval. The results of all letter ballots shall be reported to the Board at its next meeting.

Section 8. A quorum of the Board shall consist of a majority of its members.

Section 9. Regular meetings of the Board shall be held during the annual convention of the Association, on such days as may be decided by the Board. Other meetings may be held at the direction of the President, or at the request, in writing, of five members of the Board, and on such notice as shall be provided in the By-Laws.

Section 10. No Board Member may be represented in any action required of him as a Board Member by any other person; nor may he vote, by letter, upon any matter scheduled for consideration at a duly called meeting of the Board.

ARTICLE V

(Articles of Organization)

Nomination and Election of Officers and Directors

Section 1. There shall be a meeting of the Board held in January of each year at which time a Nominating Committee of not less

than seven members including the Directors representing the various Sections of the Association shall meet under the Chairmanship of the President, and shall nominate one, and may nominate two candidates for each of the offices of President, Vice President, and Treasurer, provided that any candidate so nominated shall be an Active Member of the Association, and shall have been a member of the Board of Directors, and shall signify willingness to accept the nomination. This committee shall nominate one director each from the Membership representing the Active Members, the Associate Members, and the Corporate Members. This Committee shall report its list of nominees to the Board before the close of its January meeting, and the list shall then be mailed to the membership before February First of that year.

At any time prior to noon on the first day of March of each year additional nominations may be made by request to the Secretary, signed by at least twenty-five Active Members, and upon receipt of such request, the Secretary shall, after acceptance of the nomination by the candidates, add such names to the ballot prepared by him. The nominees of the Nominating Committee shall be so designated on the ballot for each office, and the names of all nominees shall be arranged in alphabetical order.

When more than one person is nominated for any office, the election shall be by letter ballot. Each Member shall be entitled to vote for one candidate for the office of President, one candidate for the office of Vice President, one candidate for the office of Treasurer, and one candidate for each of the classes of directors named above. The ballot shall be prepared by the Secretary and mailed to each Member of the Association prior to April First in each year, and shall state the name and residence of each candidate.

The ballot shall be sealed separately in a special ballot envelope, and the latter shall be enclosed in a larger envelope, and mailed to the Secretary. The signature of the Member voting shall appear on the outer envelope.

When a letter ballot is necessary, the Secretary together with two or more Tellers appointed by the President shall meet at a time and place directed by the President, and shall open and count all ballots cast by persons entitled to vote. No ballot shall be counted if received later than noon of the 30th day following the date of mailing of the letter ballots.

The report of the Tellers for the election of the incoming President, Vice President, and Treasurer and Directors shall be declared by the President at the annual convention on certificates of the Tellers. The candidates who shall have received the highest number of votes cast for the several offices shall be declared elected. If there be a tie vote the President shall order a ballot to be taken to decide which of the candidates who have received the same number of ballots shall be chosen.

When only one candidate is placed in nomination for each office to be filled, the report of the Nominating Committee shall be considered as an election.

Section 2. The terms of the Officers so elected shall commence at the beginning of the last day of the annual convention, following the date of their election; and shall cease at the beginning of the last day of the next annual convention. But, if an annual convention is not held prior to July 1, that date will be the date of the beginning of the term of office of an officer. Said term shall be for approximately one year, but shall continue until a successor has been chosen.

In case of a vacancy in the office of President, the Vice President shall act in his place for the unexpired term. In case the Vice President cannot act, the latest living Past President shall do so.

In the case of a vacancy in the office of Treasurer, the Executive Committee shall appoint an Active Member to fill the office for the unexpired term.

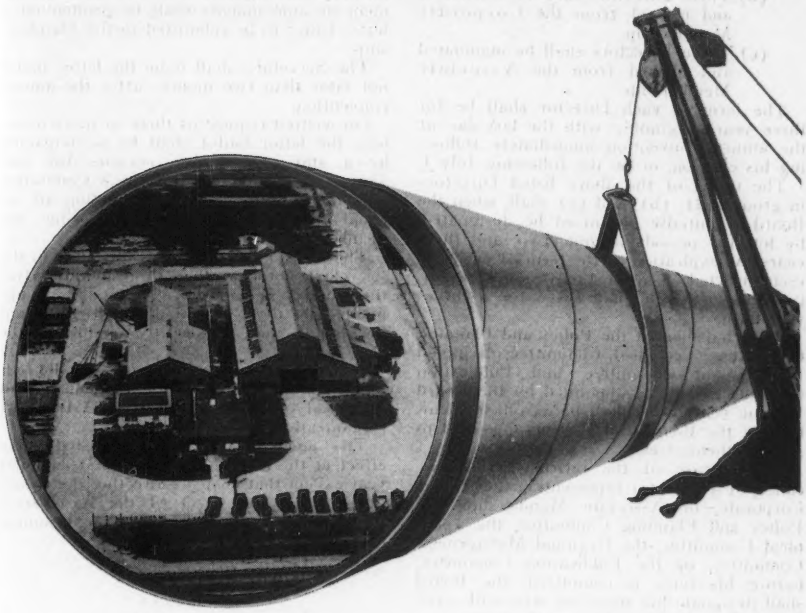
Section 3. One Director to represent each Regional Division shall be nominated and elected by the members of the Division in the same manner as the Presiding Officer of that Division is elected. The manner of such election shall receive the approval of the Board. The Director so elected shall be an Active Member and shall reside in the territory of the Division at the time of his election. Should he cease to reside in the territory of the Division before his term of office is ended, it shall be within the power of the Division to replace him.

The term of each Director so elected shall be for approximately three years, beginning with the last day of the annual convention immediately following his election, or on the following July 1. When a new Regional Division is established, the initial term of the Director representing such Section shall be as determined by the Board.

In the case of the retiring, from any cause, of a Director representing a Division, before his term is completed, the governing body of the Division shall designate his successor who shall serve for the unexpired portion of the term.

Section 4.

(a) Three Directors shall be nominated and elected from the Active Membership.



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(b) Three Directors shall be nominated and elected from the Corporate Membership.
(c) Three Directors shall be nominated and elected from the Associate Membership.

The term of each Director shall be for three years beginning with the last day of the annual convention immediately following his election, or on the following July 1.

The terms of the above listed Directors in groups (a), (b), and (c) shall, when the Board is initially organized be designated, by lot, for periods of one, two, and three years. At expiration of the term of each Director elected when the Board is first organized, his successor shall serve for a three-year term.

The Chairmen of the Policy and Planning Committee, Technical Committee, Regional Management Committee, and Publication Committee shall be appointed by the Board for one year term, shall be ex-officio members of the Board and may be appointed to succeed themselves.

In the case of the retiring, from any cause, of a Director representing the Active, Corporate, or Associate Membership, the Policy and Planning Committee, the Technical Committee, the Regional Management Committee, or the Publication Committee, before his term is completed, the Board shall designate his successor who will serve for the unexpired portion of the term.

ARTICLE VI

(Articles of Organization)

Amendments

Proposals to amend these Articles of Organization may be submitted to the Board in writing, signed by at least ten Members of the Association.

The Board shall consider the proposals, and the proposers shall be notified of the Board's opinion in regard thereto not later than the first day of March.

The proposers may then withdraw their proposals, accept any change suggested, or insist on the original form, sending their decision to the Secretary not later than the first day of April.

The proposals, as accepted by the proposers, shall be mailed to the Members not less than twenty-one days before the annual convention.

Proposals to amend these Articles of Organization may also be made by the Board and shall be mailed to the Members not less than twenty-one days before the annual convention.

All proposals shall be submitted for discussion at the annual convention.

The Members there present may propose an amendment or amendments thereto, and all proposals together with any such amendment or amendments shall be printed on a letter ballot to be submitted to the Membership.

The Secretary shall issue the letter ballot not later than two months after the annual convention.

On written request of three or more members the letter ballot shall be accompanied by a statement giving reasons for and against the proposal edited by a Committee appointed by the Board, consisting of an equal number of members favoring and members opposing the proposal.

The letter ballot shall be returnable to the Secretary not later than three months after the annual convention. Three tellers appointed by the board shall forthwith count the ballots and report the result to the Board.

An affirmative two-thirds of all valid ballots shall be necessary for the amendment or repeal of any part of these Articles of Organization.

The amendments as passed shall take effect at the beginning of the next calendar year except that changes affecting the tenure of office of an Officer of the Association shall not take effect until the next annual convention.

ARTICLE I

(By-Laws)

Admission and Expulsion

Section 1. Applications for Active, Junior, Corporate, or Associate Membership shall be made on the forms provided by the Association. Each application shall embody a concise statement of the applicant's qualifications for membership. All applications shall be forwarded to the Secretary who shall submit them to the Executive Committee.

An affirmative vote of a majority of the Executive Committee shall elect and the applicant shall become a member when his dues shall have been paid.

Section 2. No member whose dues are in arrears for three months shall receive the publications of the Association until such arrears are paid. Members in arrears for one year shall be automatically dropped by the Secretary from the list of members.

Section 3. The Board may, for sufficient cause, temporarily or permanently excuse from the payment of annual dues, any member who from ill health, advanced age, or other good reason, is unable to pay such dues, and the Board may waive the whole or part of dues in arrears, or accept in lieu thereof desirable additions to the library or collections.

Section 4. A member who has been dropped for nonpayment of dues may be reinstated by the Board on payment of the

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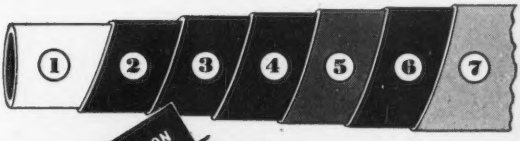
SPECIFICATION "A"

INCLUDES
(1) Mechanical cleaning.
*(2) Mechanical priming with desired primer.
(3) Hot application of desired coating.
(4) Hot application of desired coating.
(5) One spiral wrapping of desired wrapping material.
(6) One spiral wrapping of heavy kraft paper.



SPECIFICATION "B"

INCLUDES
(1) Mechanical cleaning.
*(2) Mechanical priming with desired primer.
(3) Hot application of desired coating.
(4) Hot application of desired coating.
(5) One spiral wrapping of desired wrapping material.
(6) Hot application of desired coating.
(7) One spiral wrapping of heavy kraft paper.

PROTECTIVE COATING MATERIALS AVAILABLE ON ABOVE SPECIFICATIONS

- Asphalts
- Barrett Millwrap Enamel
- Barrett Pipe Line Enamel
- Barrett Waterworks Enamel
- Bitumastic Regular Enamel
- Bitumastic 70-B Enamel
- Bitumastic XXH Enamel
- Ennjay Enamel
- *No-Ox-Id
- Reilly Filled Pitch Enamel
- Reilly No. 230 Enamel

*Primer not required with No-Ox-Id coatings.

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arrears. He shall then be entitled to receive such back numbers of the publications of the Association as may have been withheld from him on account of nonpayment of dues and are available for distribution.

Section 5. Any member of any grade may be expelled from membership in the Association by a three-quarters vote of the Board, taken by letter ballot, provided such member has been given a written statement of the charges preferred, and has been accorded an opportunity of a hearing before the Board.

Section 6. Any member may retire from membership by giving written notice to the Secretary, provided that he is in good standing.

ARTICLE II

(By-Laws)

FEES AND DUES

Section 1. Each ACTIVE MEMBER shall pay annual dues of seven dollars and fifty cents ($7.50).

Section 2. Each JUNIOR MEMBER shall pay annual dues of two dollars and fifty cents ($2.50).

Section 3. Each CORPORATE MEMBER shall pay annual dues of one hundred dollars ($100.00).

Section 4. Each ASSOCIATE MEMBER shall pay annual dues of one hundred dollars ($100.00).

Section 5. The fiscal year of the Association shall begin on January First, and terminate on December Thirty-First. Annual dues shall be payable in advance, and shall be due on January 1st in each year. It shall be the duty of the Secretary to notify each member on or before December Thirty-First in each year of the amount due from said member for the ensuing year.

Section 6. Any newly elected member shall be entitled to all of the publications of the Association that are distributed to its members during the year, or that part of the year, for which he has paid dues.

ARTICLE III

(By-Laws)

POLICY AND PLANNING COMMITTEE

There shall be a Policy and Planning Committee of six (6) members. This Committee shall be appointed by the Board, so that one-third of its membership shall be replaced each year, in order that all members will serve a three-year period.

The President and Secretary shall be ex-officio members.

The duties of the Committee shall be to assist in planning the Association's future activities, to act in an advisory capacity to the Board on policy matters, and to act upon all matters of long term policy and changes in the functions of the Association before presentation for formal action of the Board.

ARTICLE IV

(By-Laws)

EXECUTIVE COMMITTEE

There shall be an Executive Committee of five members consisting of the President and four Directors. This Committee shall be chosen annually by the Board.

The President of the Association shall act as Chairman of the Committee, or in his absence, Committee shall choose a temporary Chairman from its members, and the Secretary of the Association shall act as its secretary.

The duties of the Committee shall be to direct the administrative work of the Association and to carry out the policies of the Board between meetings of the latter.

A quorum of the Committee shall consist of three members.

ARTICLE V

(By-Laws)

COMMITTEES

Section 1. A Technical Committee shall be appointed annually by the Board. It shall consist of at least ten members, at large, and its Chairman shall be ex-officio, a member of the Board.

Any resolution, report or publication which undertakes to establish in the name of the Association, or any of its Sections or Divisions, professional or technical standards, shall be submitted to this Committee, and it shall direct all such matters on behalf of the Association.

It shall appoint such Subcommittees as it may deem necessary to carry on its work properly, to further the technical and research activities of the Association.

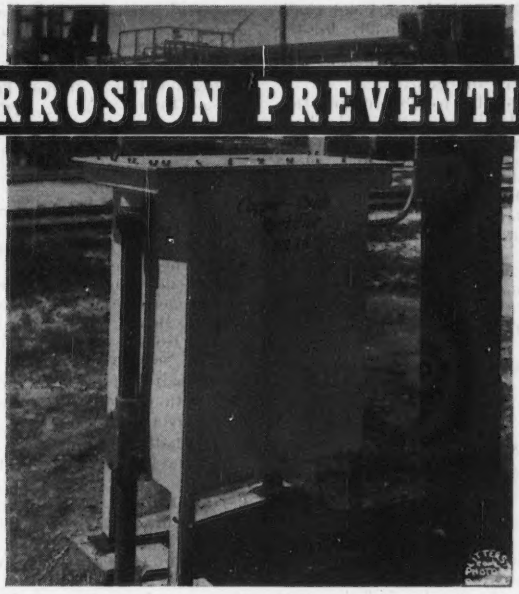
Section 2. A Publication Committee shall be appointed annually by the Board. It shall consist of at least five members, at large, and its Chairman shall be ex-officio, a member of the Board.

It shall have control of the publications of the Association, including the programs of its conventions and shall see that all publications and papers comply with the Association's policy before publication.

The Committee shall prepare rules which shall govern the preparation, presentation, acceptance ,and publication of all papers and such other matters of a similar nature as the best interests of the Association may require.

It shall appoint such subcommittees as it may deem necessary to carry on its work properly, to further the technical and research activities of the Association.

CORROSION PREVENTION



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Section 3. A Regional Management Committee shall be appointed annually by the Board. It shall consist of at least five members, at large, and its Chairman shall be, ex-officio, a member of the Board.

It shall be responsible for the organization of the Regional Divisions and Local Chapters and shall prepare and assist in the execution of the policies, activities, plans and agenda. It shall also provide the channel through which all Association and Board policies and actions necessary to the development of Divisions and Chapters shall be handled.

It shall assist and advise in the organization and development of Regional Divisions with their Local Chapters and shall coordinate the work of such Divisions and Chapters.

Section 4. The Board shall appoint such other Committees as may be necessary to carry on the work of the Association.

ARTICLE VI

(By-Laws)

DUTIES OF OFFICERS AND DIRECTORS

Section 1. The President shall have general supervision of the affairs of the Association, and shall preside at all conventions of the Association and meetings of the Board. In his absence, he shall designate a Presiding Officer to act in his stead at such conventions or meetings. He shall be, ex-officio, a member of all Committees.

Section 2. The Vice President shall assist the President in the performance of his duties, and act in his stead when required. He shall be, ex-officio, a member of all Committees.

Section 3. The Board of Directors shall be the legal representatives of the Association, and as such shall have full control of the Association in regular convention. It shall make the necessary arrangements for the conventions, and shall have power to expend the funds of the Association, or to invest the same, but must not incur indebtedness beyond the funds in the hands of the Treasurer and Secretary. It shall hold convention meetings, one during the last day and one meeting at least one hour before the opening session of each annual Convention. Other meetings shall be held at the call of the President, or of any five members of the Board.

Notice of all meetings shall be issued by the Secretary at least 15 days in advance of such meetings to all members of the Board.

At the meeting on the last day of the convention, the Board shall appoint the Secretary, who shall serve until the close of the next annual convention or until his successor shall have been appointed. If no annual convention is held prior to July 1, in any calendar year, the incoming Board of Directors shall appoint the Secretary as soon after July 1 as may be found feasible by said Board.

Except as otherwise provided in the Articles of Organization and By-Laws, all questions before the Board shall be decided by a majority vote.

Section 4. The Treasurer shall have charge of the funds of the Association and shall pay bills against the Association when signed by himself and the Secretary. He shall make such reports to the Board as may be necessary or as may be called for by said Board. He may, with the approval of the Board, establish a drawing account for the Secretary.

He shall be bonded at the expense of the Association, and to an amount to be determined by the Board.

He shall perform such other duties as may be assigned to him by the Board.

Section 5. The Secretary shall be a Member of the Association or may be employed as Executive Secretary by the Board. It shall be his duty to attend all conventions and meetings of the Association, and of the Board, prepare the business and duly record the proceedings thereof. He shall see that all moneys due the Association are collected, and shall promptly deposit the same to the credit of the Association. He shall certify to all bills against the Association, and once each month he shall forward to each member of the Board a financial summary of receipts and disbursements.

The Secretary shall have charge of the printing and distribution of the Proceedings and Transactions of the Association to all the members.

He shall be, ex-officio, a member and Secretary of the Technical Committee, the Regional Management Committee, the Executive Committee, the Policy and Planning Committee, and of the Publication Committee.

He shall make such reports to the Board as may be necessary or may be called for by the Board.

He shall have charge of the books and records of the Association and shall supervise the work of all employees.

The Books of the Association shall be audited annually by Certified Public Accountants, to be appointed by the Board.

He shall be bonded at the expense of the Association, and to an amount to be deterbined by the Board. He shall perform such other duties as shall be assigned to him by the Board.

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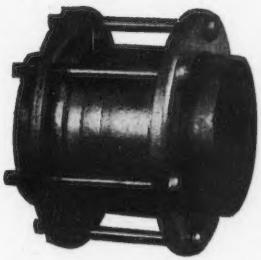

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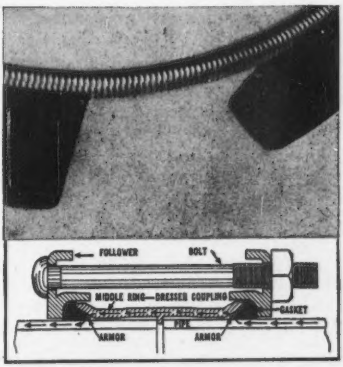

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ARTICLE VII
(By-Laws)
CONVENTIONS OF THE ASSOCIATION

The annual convention of the Association shall be held at a time and place to be selected by the Board. Additional conventions of the Association may be held at such times and places as may be selected by the Board. Meetings of the Regional Divisions and Local Chapters shall be held as determined by the Constitutions of the Regional Divisions. All conventions and meetings shall be conducted according to "Robert's Rules of Order."

Each member and guest present at any of the conventions of the Association shall pay a registration fee of such amount as may be determined by the Board.

ARTICLE VIII
(By-Laws)
REGIONAL DIVISIONS AND LOCAL CHAPTERS

Section 1. The Continental United States shall be divided into five (5) Regional Divisions.

Section 2. Local Chapters may be established by the Board on receipt of a written request to that effect signed by twenty Active or Corporate Members of the Association residing in the territory within which the Local Chapter is desired. The territory embraced by each Local Chapter shall be fixed by the Board.

Section 3. Such Local Chapters which shall consist only of members of this Association in good standing shall elect their own officers and committees, and may make any rules for their government not inconsistent with the Articles of Organization and By-Laws of the Association, but these rules must first be approved by the Board.

Section 4. After each Local Chapter is established and its rules have been approved by the Board, the Board may authorize the Secretary and Treasurer to disburse to each Chapter such amounts of Association funds as the Board shall determine, such funds to be provided for use by the Chapter in carrying on the purpose and policies of the Association through the activities of the Chapters.

The Treasurer of each Local Chapter shall forward to the Secretary of the Association his application endorsed by the Presiding Officer of the Chapter for such portions of the said sums above specified as may be needed and upon receipt of such application the Secretary shall authorize the Treasurer of the Association to pay such sums to the Treasurer of the Chapter. These moneys may be used by the Chapter only in payment of necessary operating expenses.

At the end of each fiscal year the Treasurer of each Chapter shall submit a certified copy of his accounts to the Secretary of the Association, the same being itemized and showing the balance on hand of funds received from the Association. These funds shall remain to the credit of such Chapter until such Chapter is dissolved or the Board shall otherwise order their return to the treasury of the Association.

Association funds in the hands of Chapters shall not be accumulated by a Chapter to an amount greater than that which it would be entitled to use in any calendar year. If at the end of one year the activities of the Chapter have not required it to use the amount of money received from the Association, the Board may direct the Secretary and Treasurer to reduce the amount which the Chapter will receive for use in the subsequent year to the extent of the balance of fund then remaining in the hands of the Chapter Secretary and Treasurer.

Section 5. Any member of the Association who resides in a locality which is not included in the territory embraced by an existing Local Chapter, may upon written request to the Board be included in the membership of any Local Chapter. The Secretary of the Association shall notify the Secretary of the Local Chapter of the enrollment of the member.

Whenever a new Local Chapter is formed or an existing Local Chapter has its territory extended which will include in its territory the locality where such member resides, he shall automatically be included in the membership of such Local Chapter.

Section 6. Any Chapter may be dissolved by the Board for reasons which it believes are good and sufficient.

ARTICLE IX
(By-Laws)
PUBLICATIONS

All publications of the Association shall be issued under the direction of the Board and shall be copyrighted as far as is practicable and proper.

ARTICLE X
(By-Laws)
AMENDMENTS

The Board of Directors may amend these By-Laws in any manner not inconsistent with the Articles of Organization by a two-thirds vote of those voting at any meeting of the Board or by sealed letter ballot, providing that a copy of such proposed amendment has been mailed by the Secretary to each member of the Board at least thirty days prior to such meeting or letter ballot.

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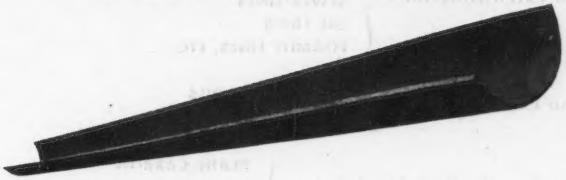

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6⅝	5/16	12.11
8⅝	5/16	15.57
10¾	5/16	19.24
12¾	5/16	22.77

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Inside Diameter of Wrap, Inches	Thickness, Inches	Weight per Pair, Lbs.
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6⅝	5/16	33
8⅝	5/16	42
10¾	5/16	52
12¾	5/16	63

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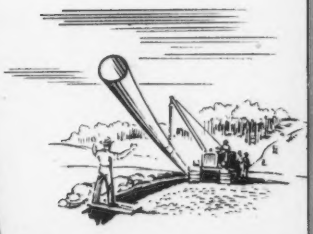

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